Inner Pixels and B-Physics

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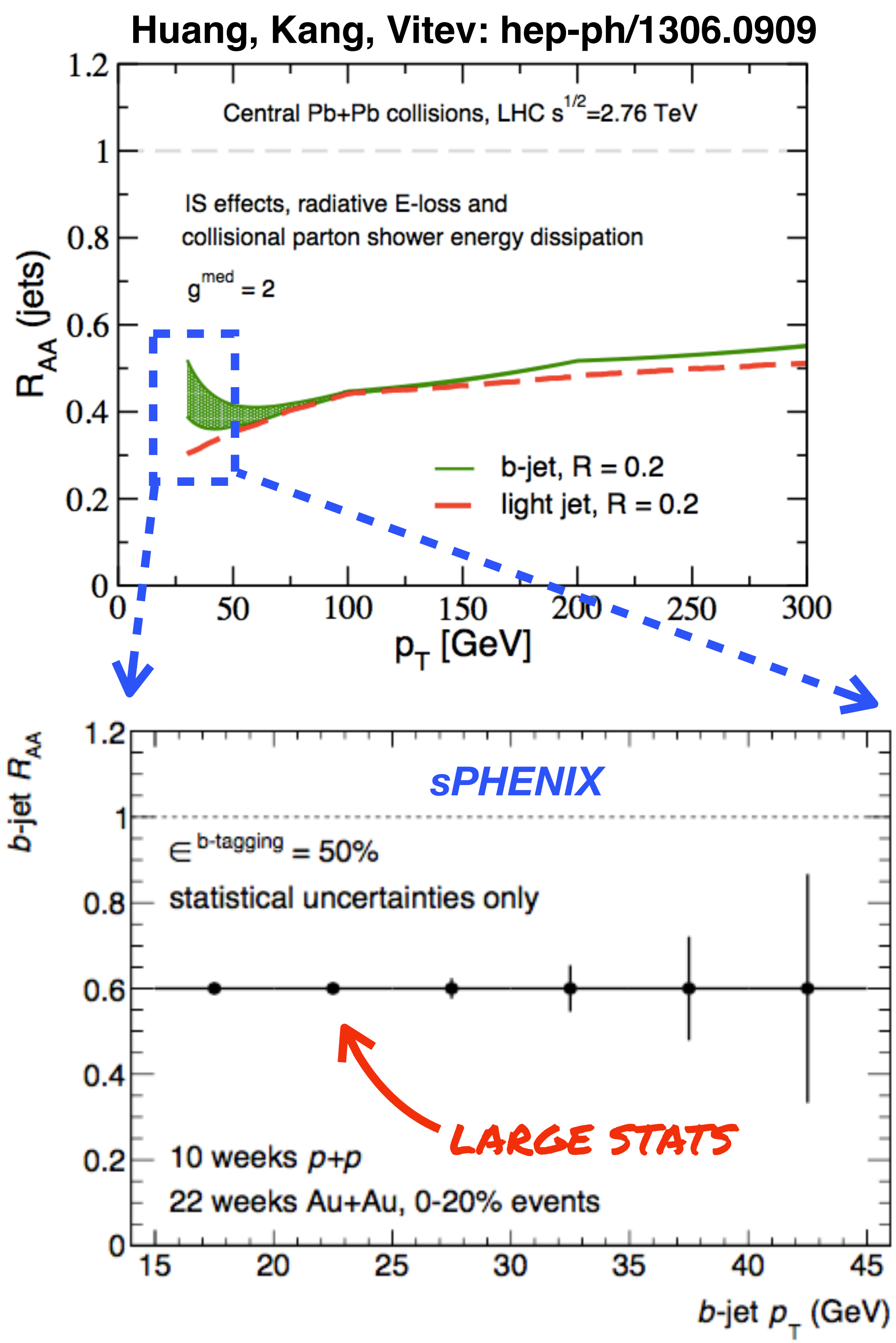
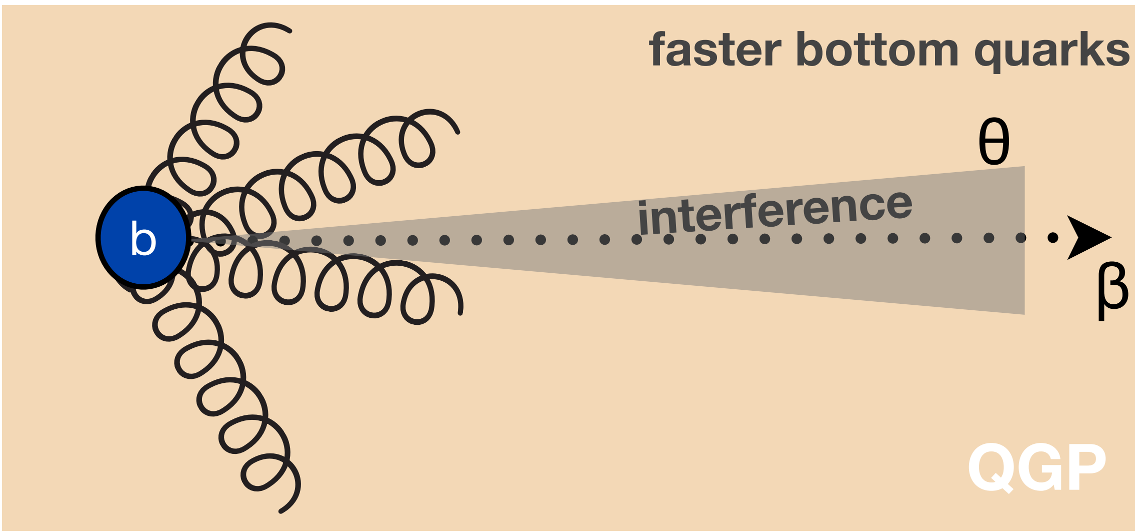
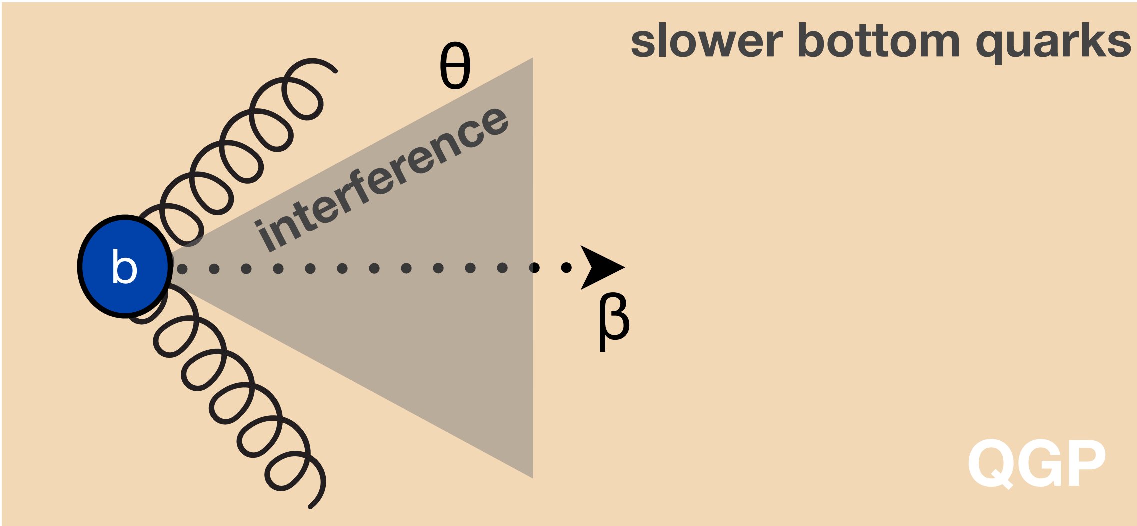
Los Alamos National Laboratory

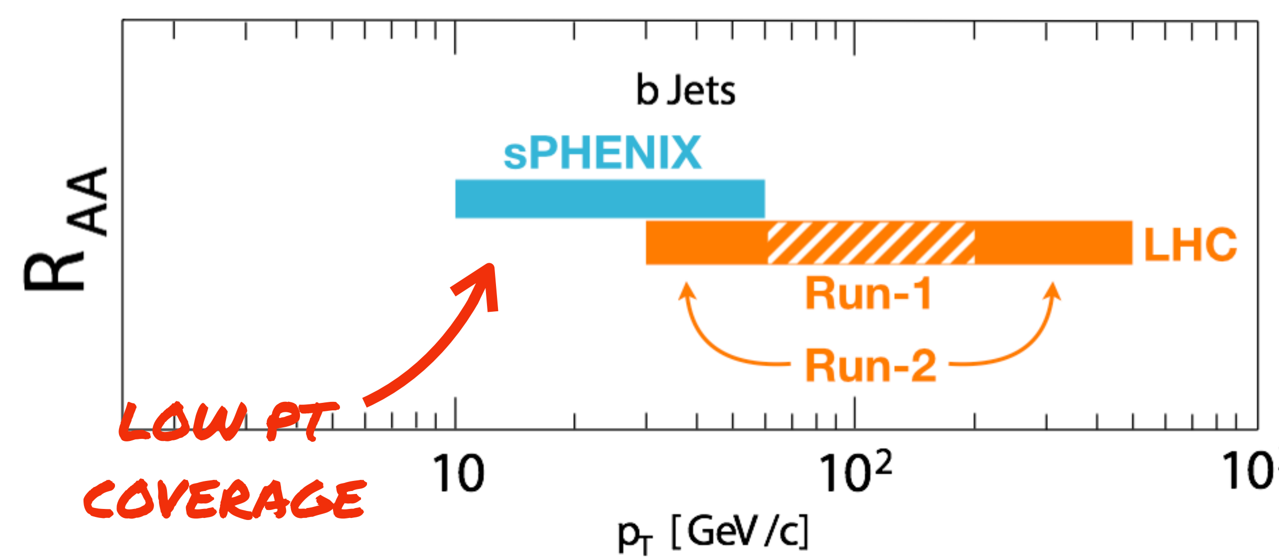
sPHENIX Tracking Workshop
Santa Fe, New Mexico
October 27th 2015

B-jet Physics: Energy Loss

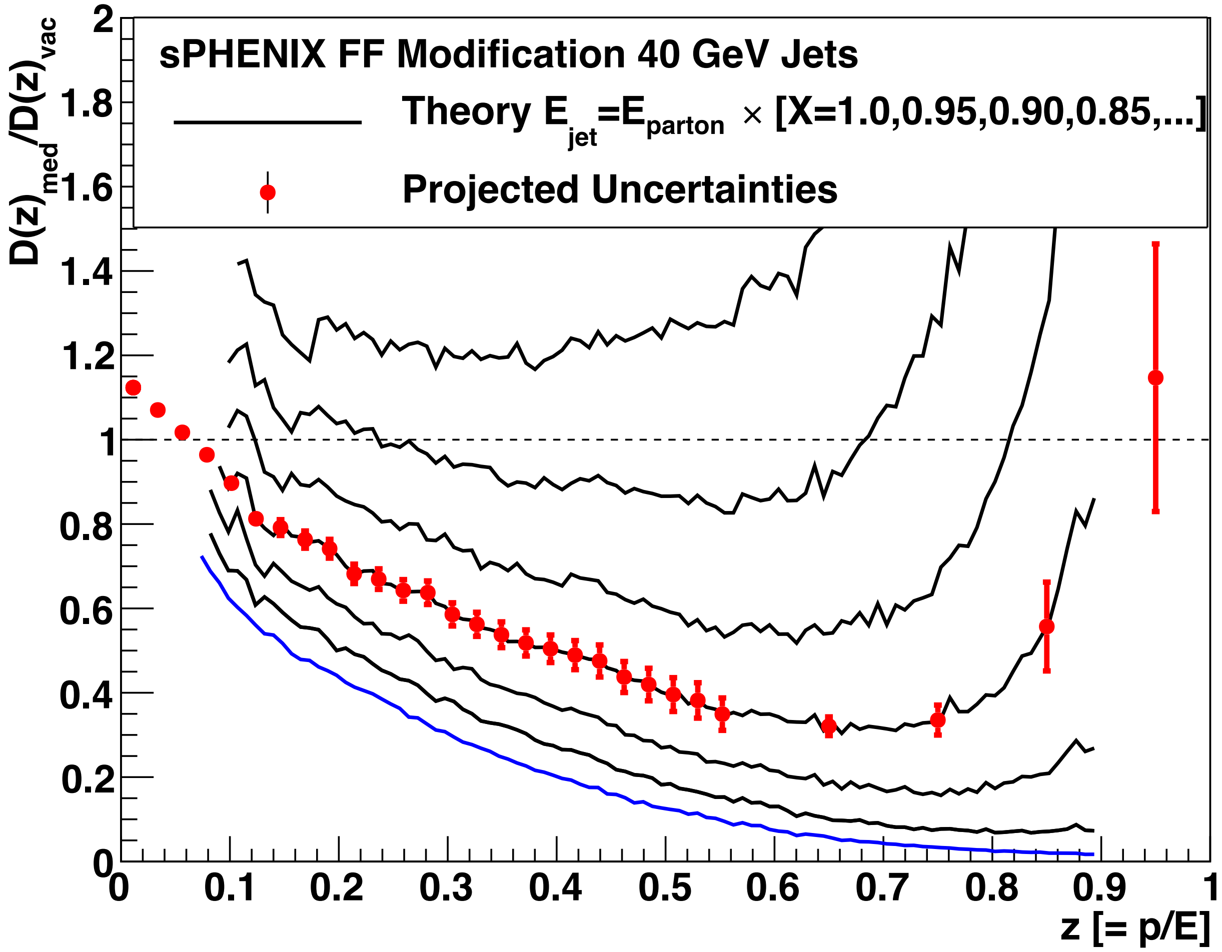


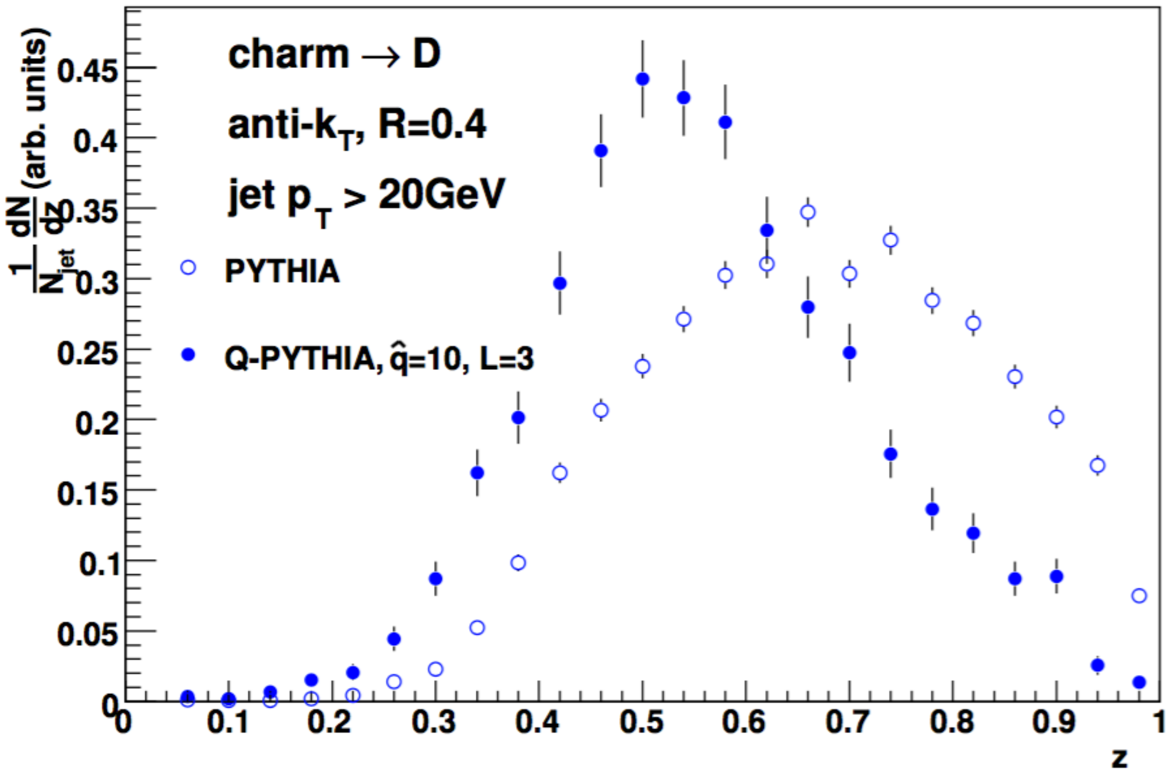






B-jet Physics: Fragmentation

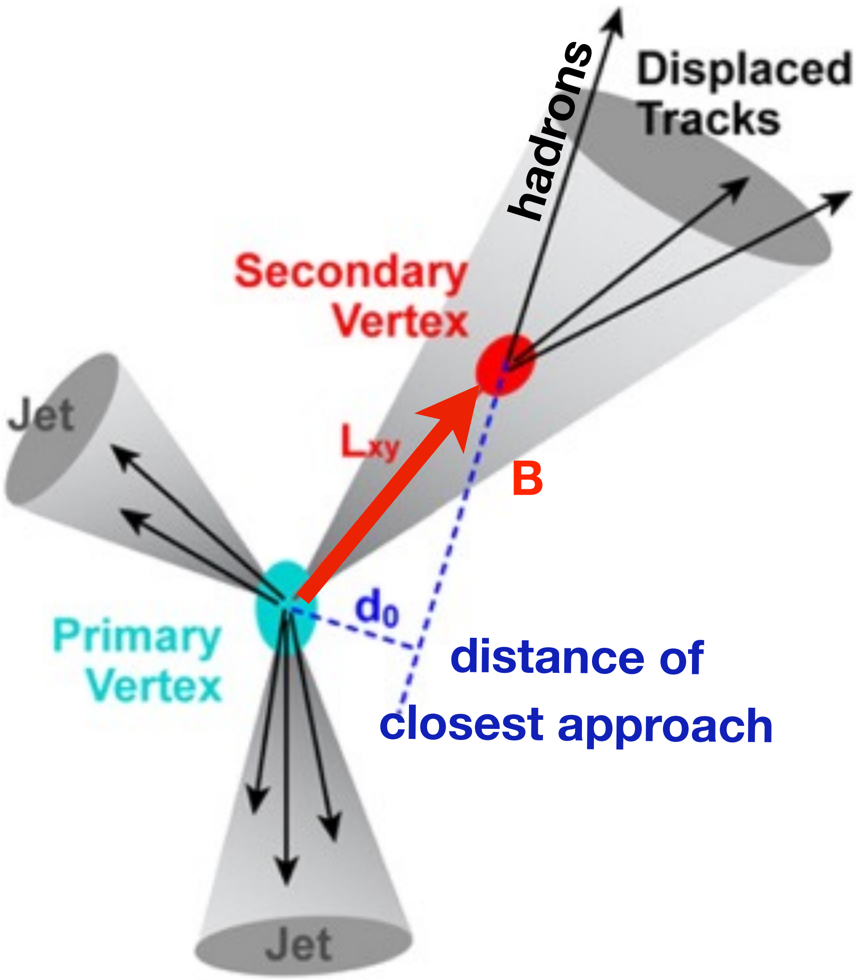




Interest in measuring both small-z (enhancement) and large-z (suppression) fragmentation

Hard fragmenting heavy-flavor provides a different underlying distribution with which to measure in-medium fragmentation

B-jet Identification Methodology



sPHENIX should have access to 3 different techniques for heavy-flavor identification:

(1) Semi-leptonic decay

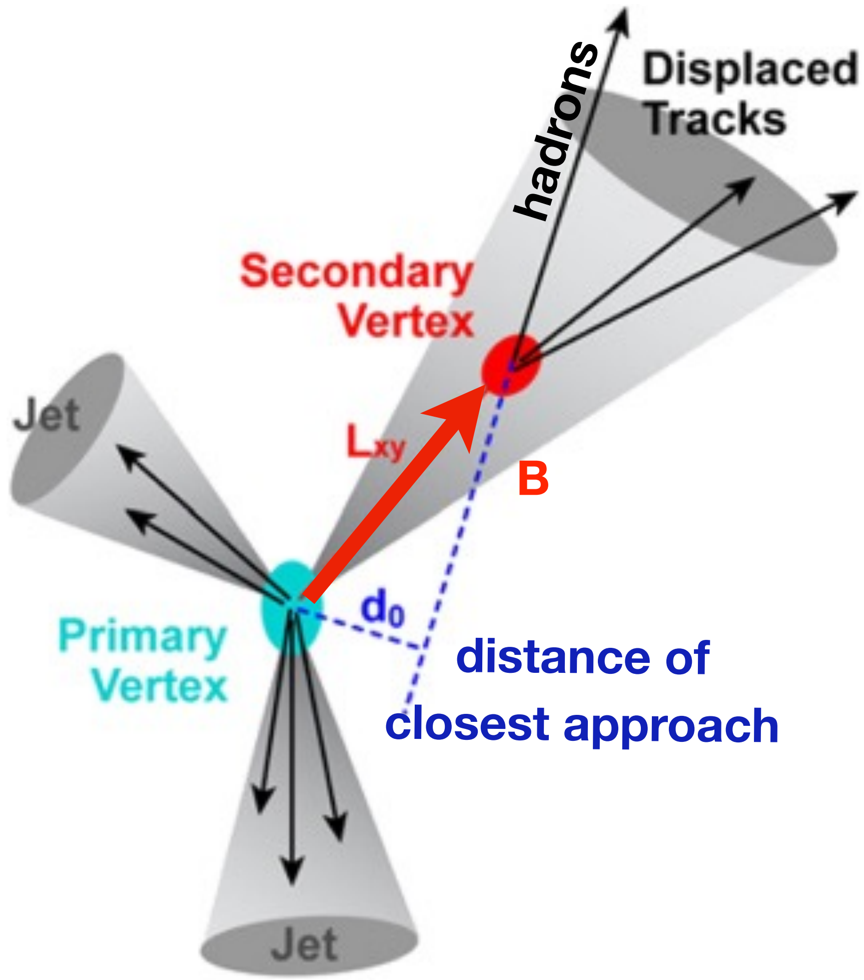
(2) Multiple Large DCA tracks

(3) Secondary Vertex Mass

Big push from DVP for sPHENIX proposal

Unexplored thus far!

B-jet Identification Methodology



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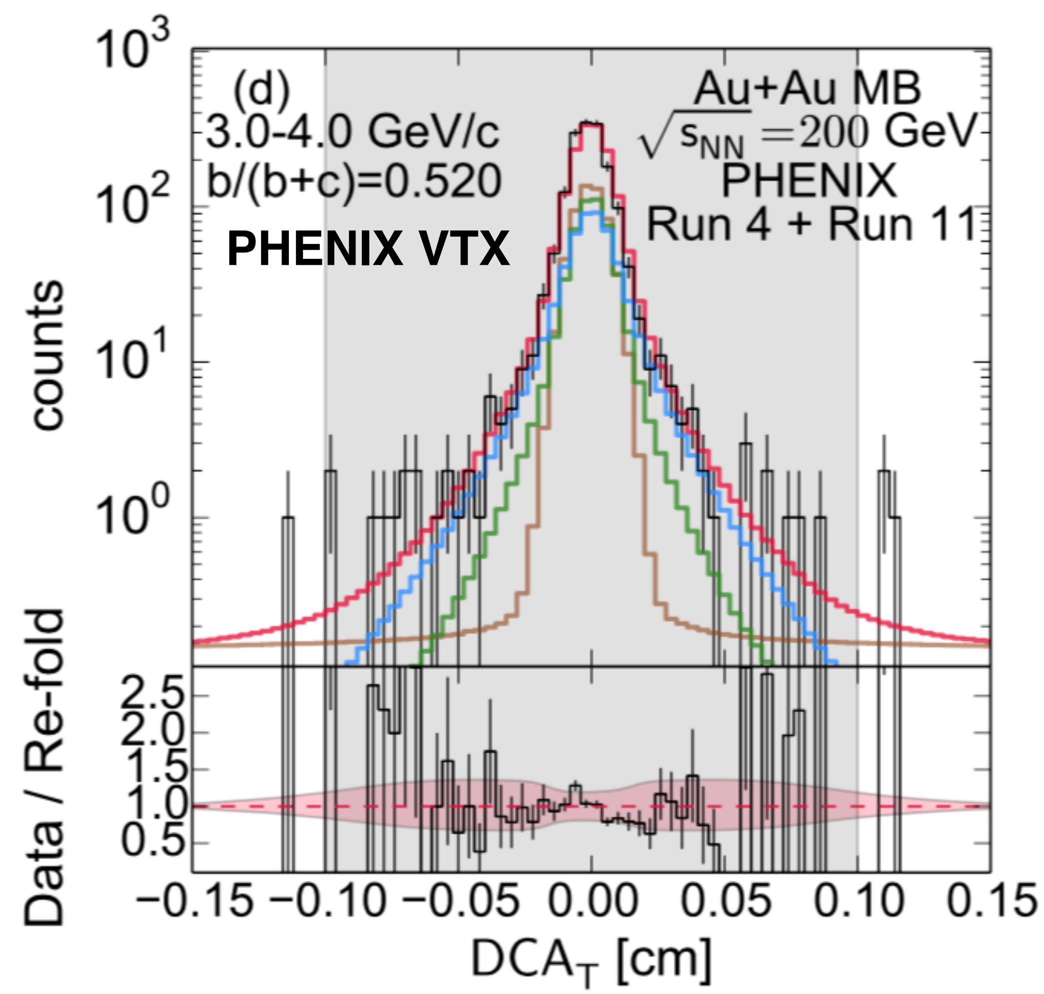
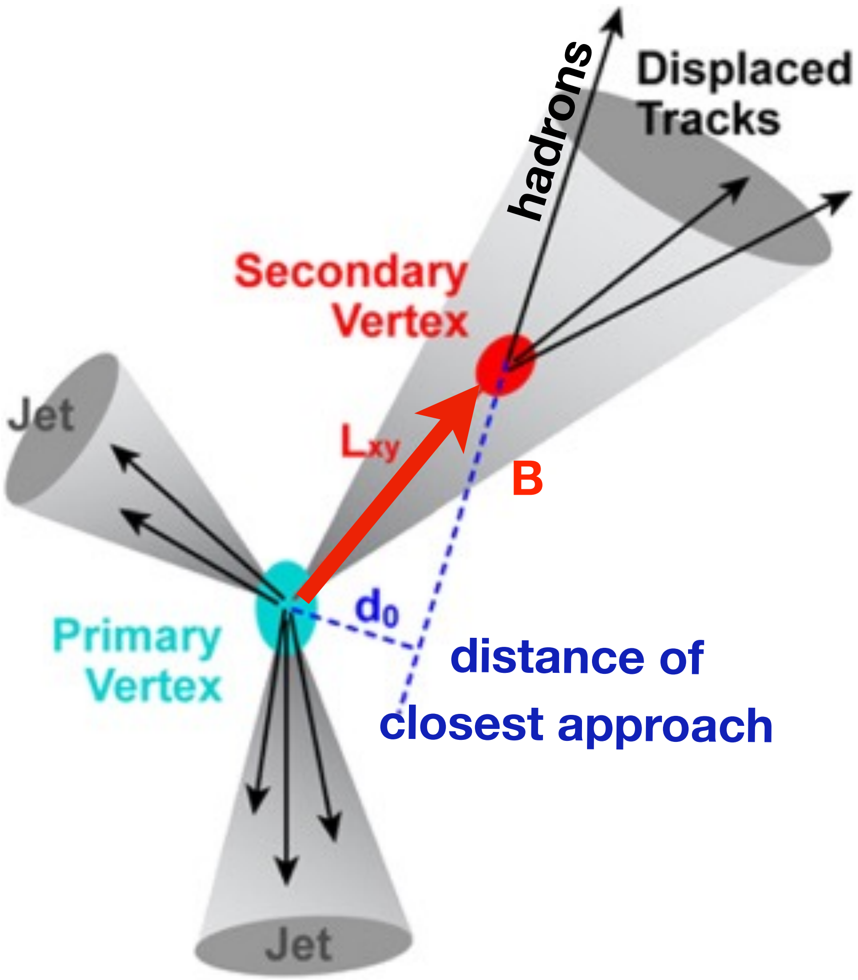
Semi-leptonic decay requirements:
Electron identification at large p_T
Narrow primary electron DCA distribution



B-jet Identification Methodology



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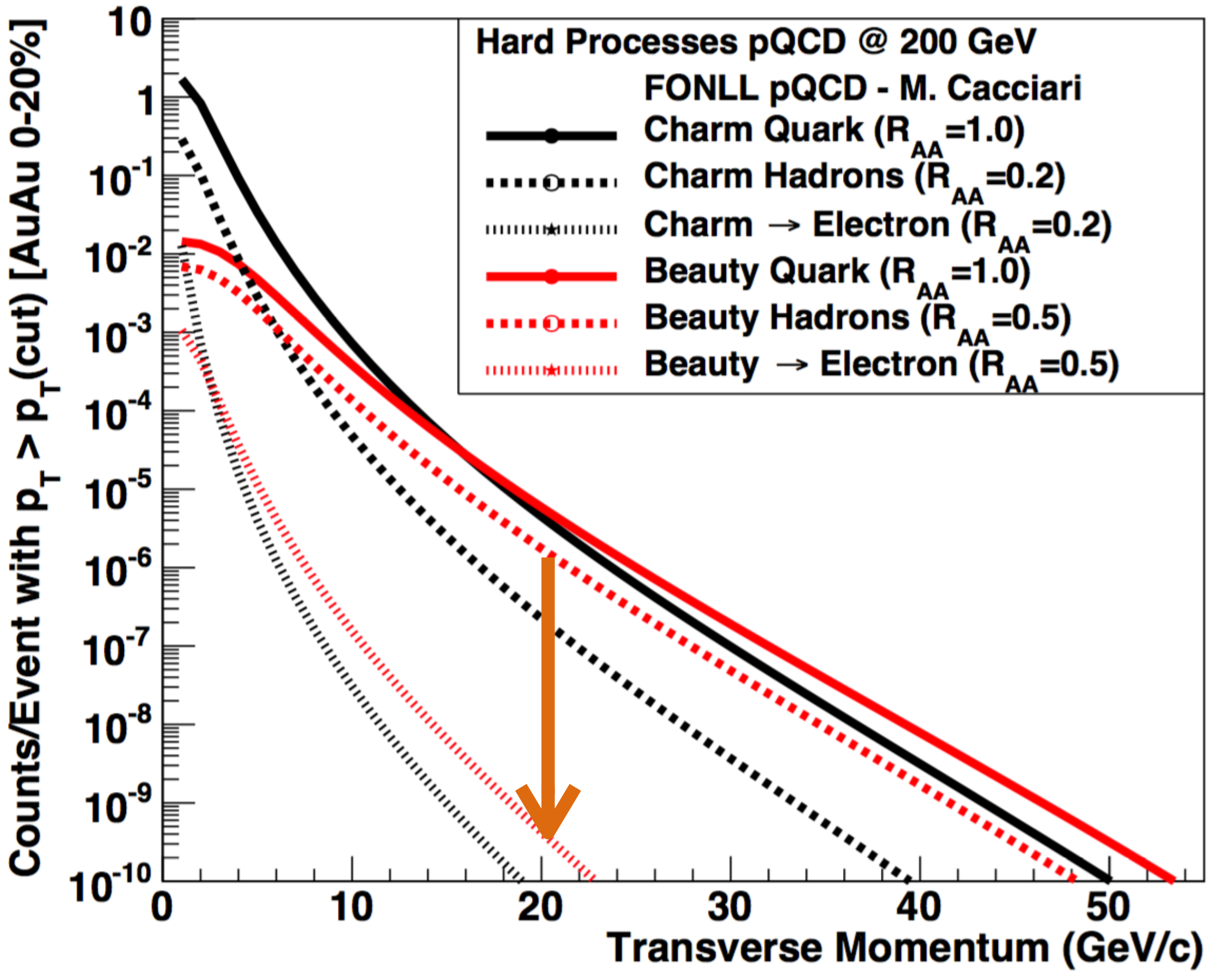


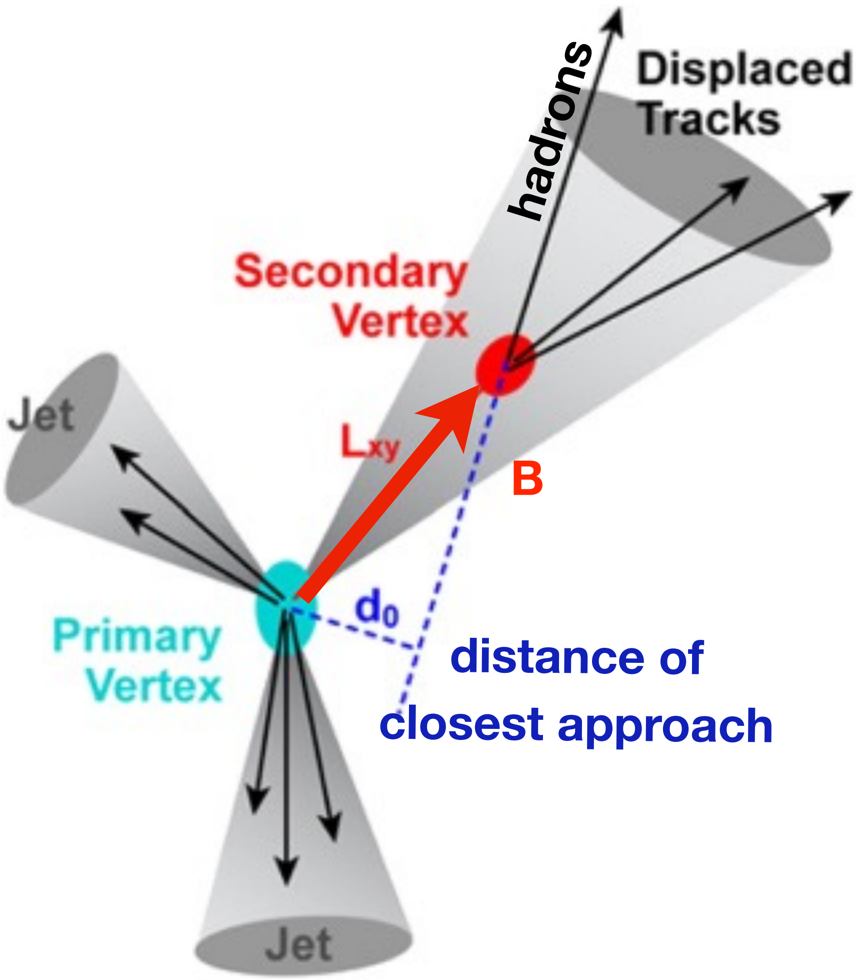
Semi-leptonic decay requirements:

Electron identification at large p_T

Narrow primary electron DCA distribution

Downside: Large reduction in B-jets if only the semi-leptonic decay channel is used

B-jet Identification Methodology



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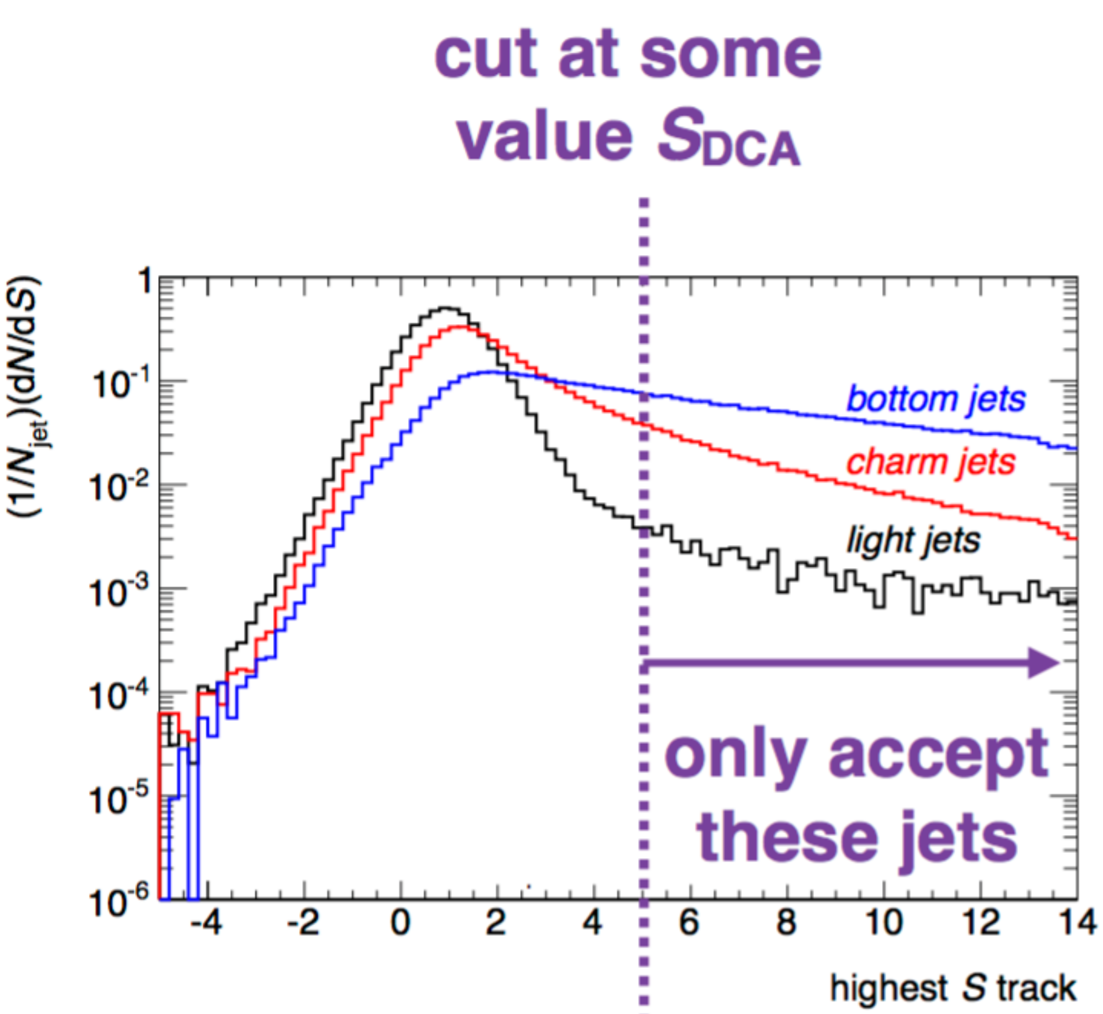


Track Counting requirements:

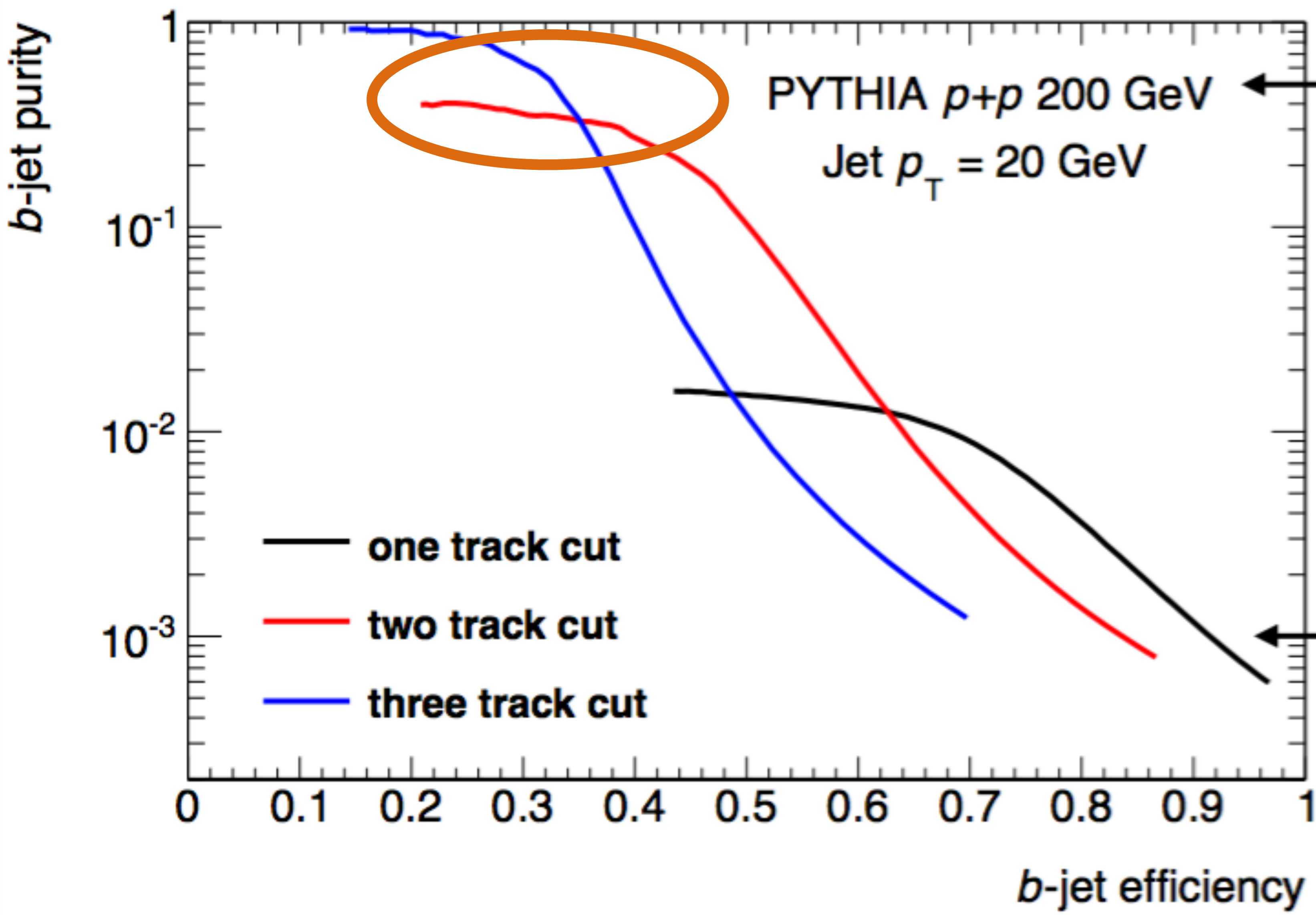
Large single particle reconstruction efficiency, $\sim\epsilon^N$

Narrow primary hadron DCA distribution (<70um)

B-jet Identification Methodology

from the April Review…

b-jet performance in *p*+*p*



Purity ~ 0.5 is achievable at reasonable efficiency!

Purity <10^{-3} before any cuts!

P vs. **E** curves for requiring **1**, **2** or **3** tracks with S_{DCA} above some minimum value

12

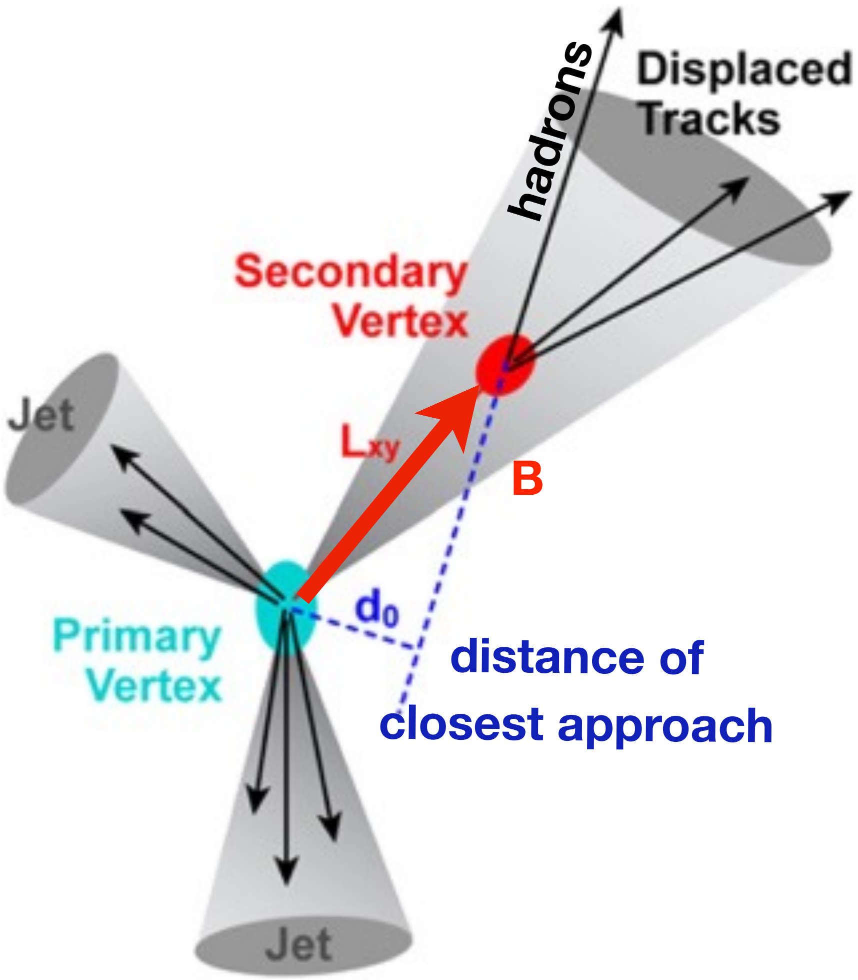
Trac

La

e

Na

B-jet Identification Methodology



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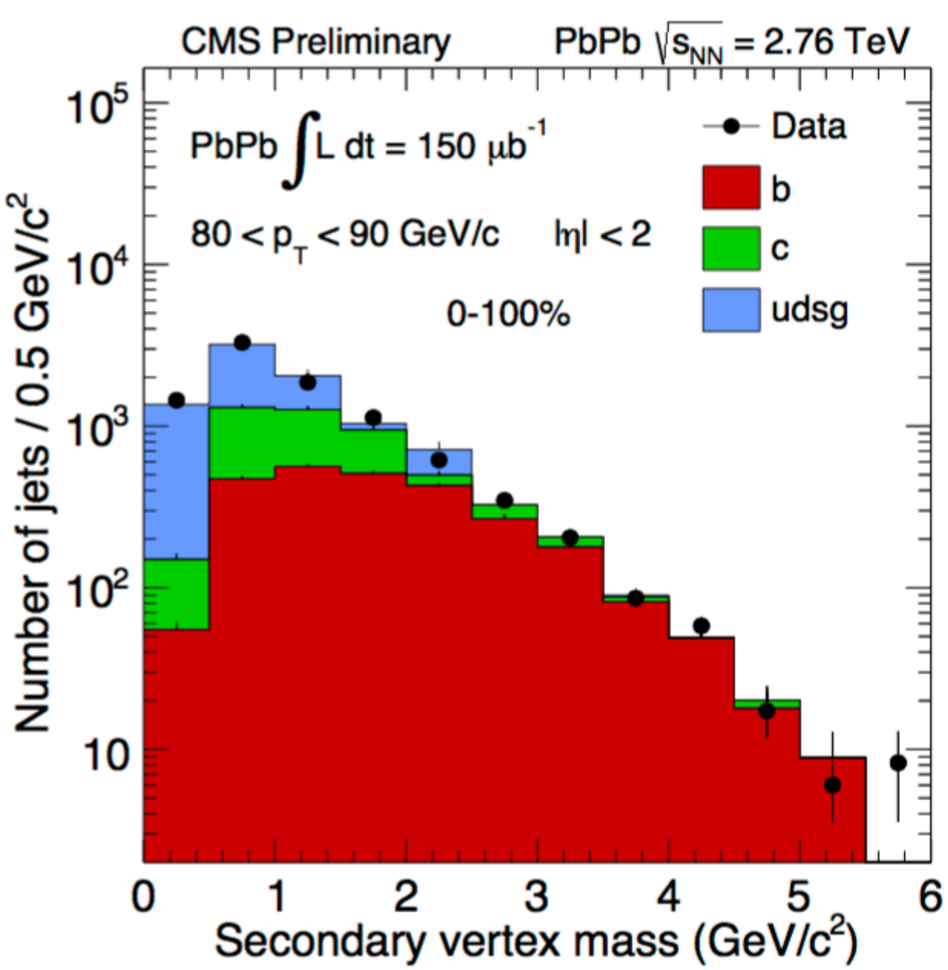


Secondary Vertex requirements:

Large single particle reconstruction efficiency, $\sim\epsilon^2$

Individual track position resolution

Missing Detector Requirements

What does our Proposal and pCDR say about b-jet id:

Heavy quark jets The key to the physics is tagging identified jets containing a displaced secondary vertex

- precision DCA (< 100 microns) for electron $p_T > 4\,\mathrm{GeV}/c$
- electron identification for high $p_T > 4\,\mathrm{GeV}/c$

The current spec doesn't define a purity/efficiency requirement and focuses only on the semi-leptonic channel for some bizarre reason.

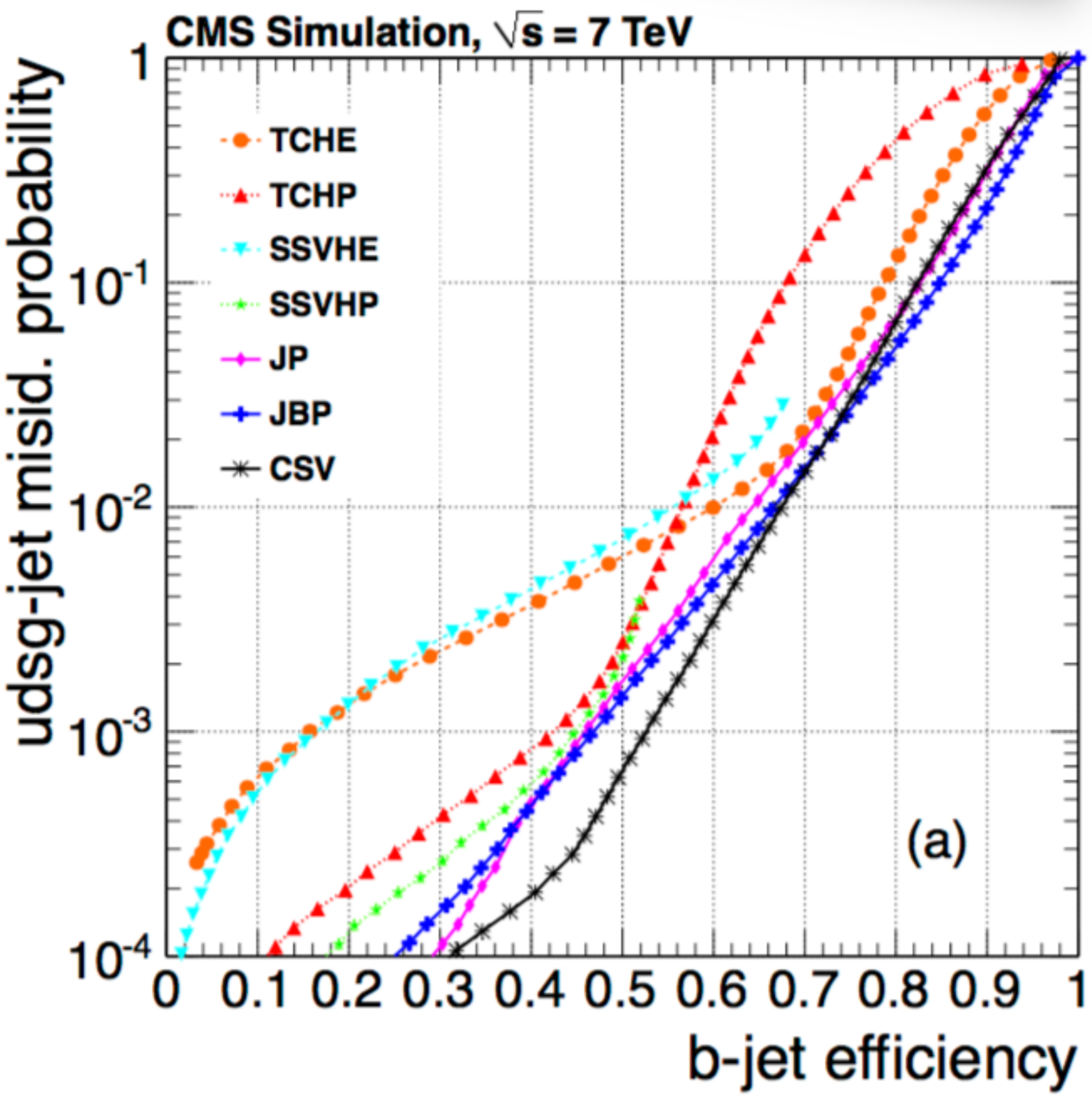
We will need to add either:

(1) charged particle tracking efficiencies
(3-track counting: ~95% will be needed)

(2) track position resolutions / better IP resolutions
(2nd vertex CMS IP resolutions ~15-30 um)
(multi-DCA needs ~70 um)

Or more generally, we should define a spec for:

(A) B-jet identification purity (contamination) and efficiency requirement
(We argued in April that:
~45% efficiency and ~35% purity in Au+Au would be comparable to CMS)

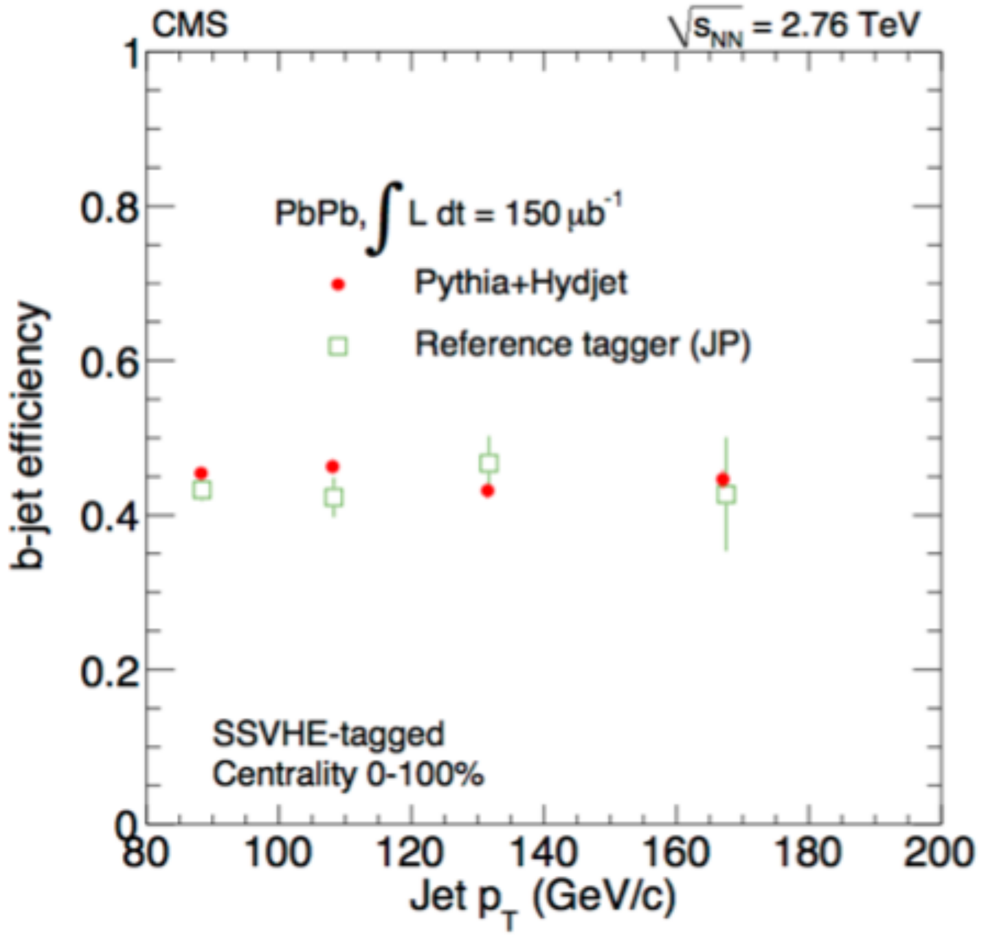


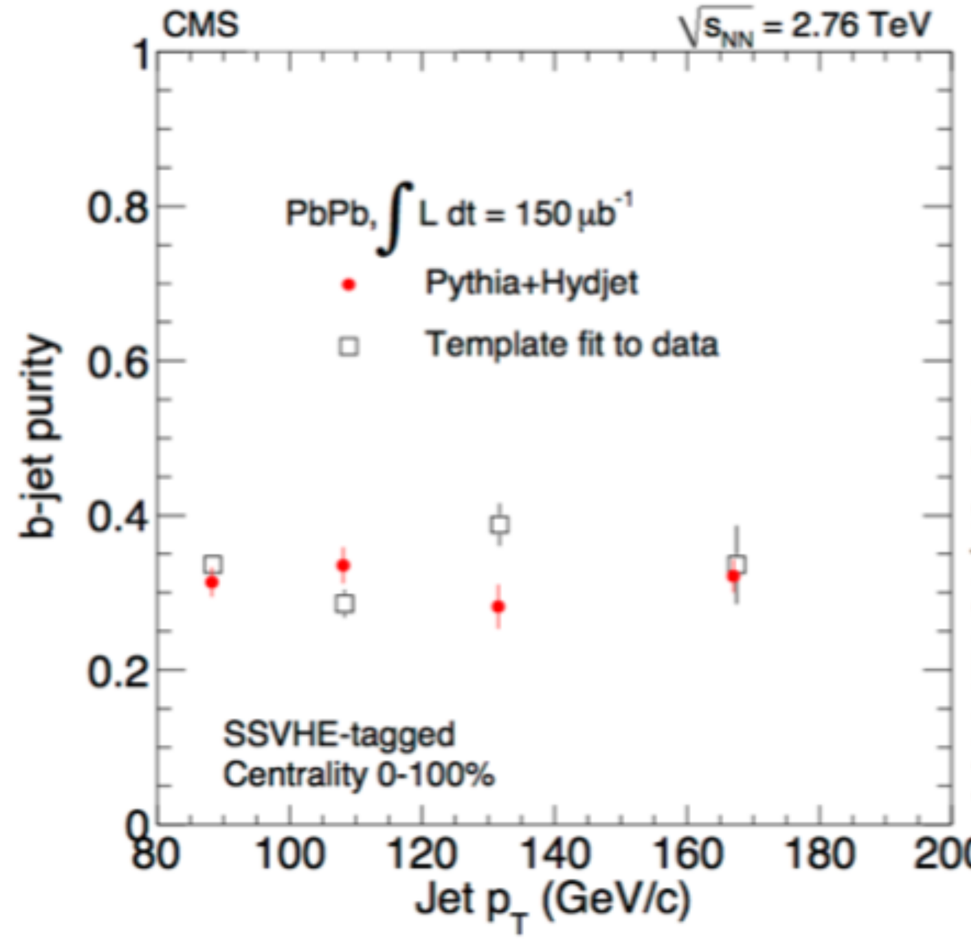
It is a big (unavoidable) job to connect these different methods and the physics to detector requirements but we can use CMS-inspired numbers in the interim

CMS b-jet Performance

from the April Review…

b-jet efficiency and purity in Pb+Pb





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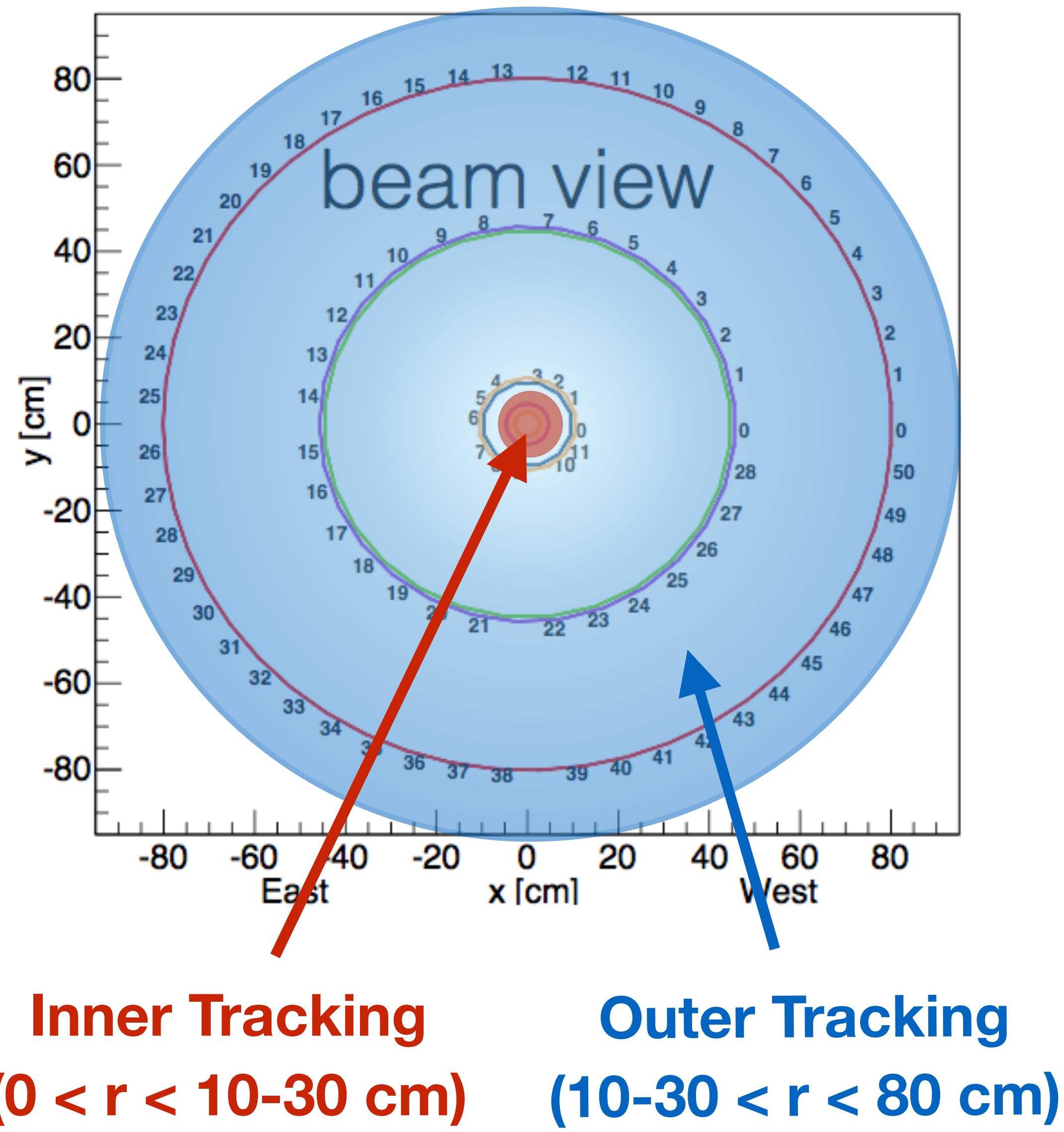
≈*45% Efficiency* and ≈*35% Purity* in the CMS *b*-jet spectrum in Pb+Pb

➡ comparable to that achievable with 2- or 3-track TrackCounting cuts

Partial Factorization: Inner Tracking Goals



Inner tracking:

(1) precision track position (DCA, 2nd vertexing)
(2) high resolution collision vertexing
(3) pattern recognition ambiguity breaking

Outer tracking:

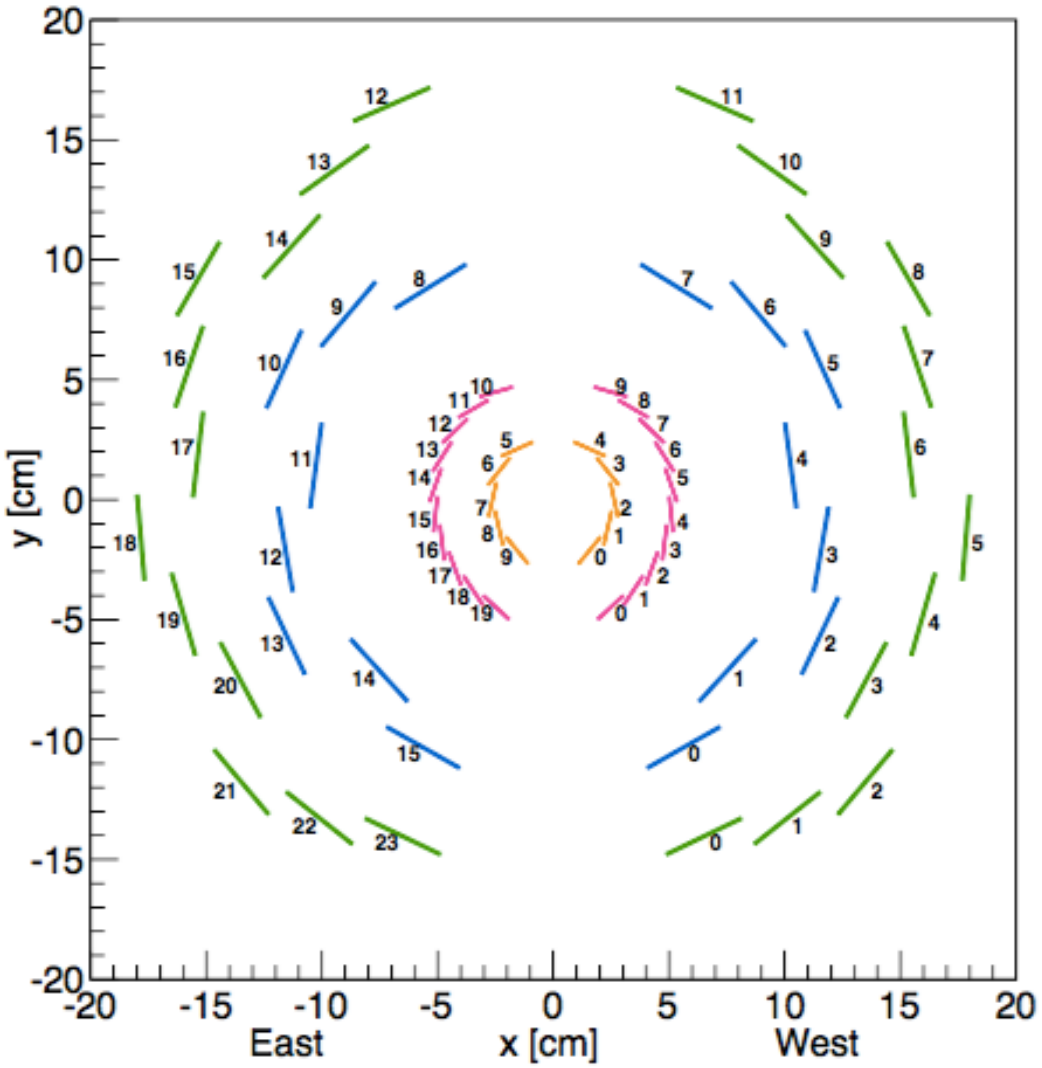
(1) momentum resolution optimization
(2) pattern recognition ambiguity breaking

"The choice between the inner tracker options is independent of the choice of outer tracker technology, and vice-versa."

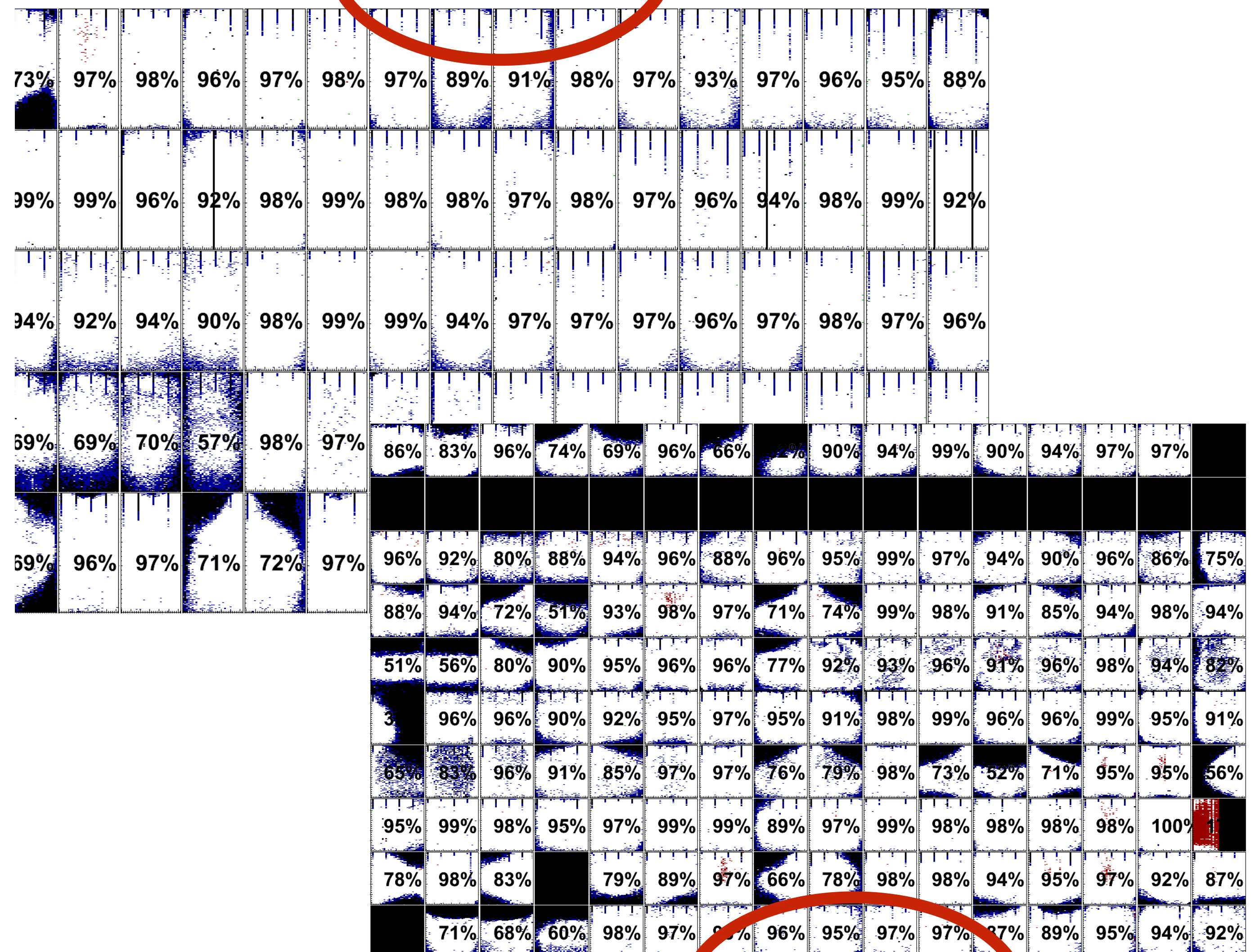
~Early Draft pCDR

For the inner tracking **technology** this is probably true (up to timing requirements), but for the **conceptual design** it is not. An inner + outer tracker will have to perform together with a **low fake rate (solve the basic pattern recognition problem)**.

Tracking Option: Pixels



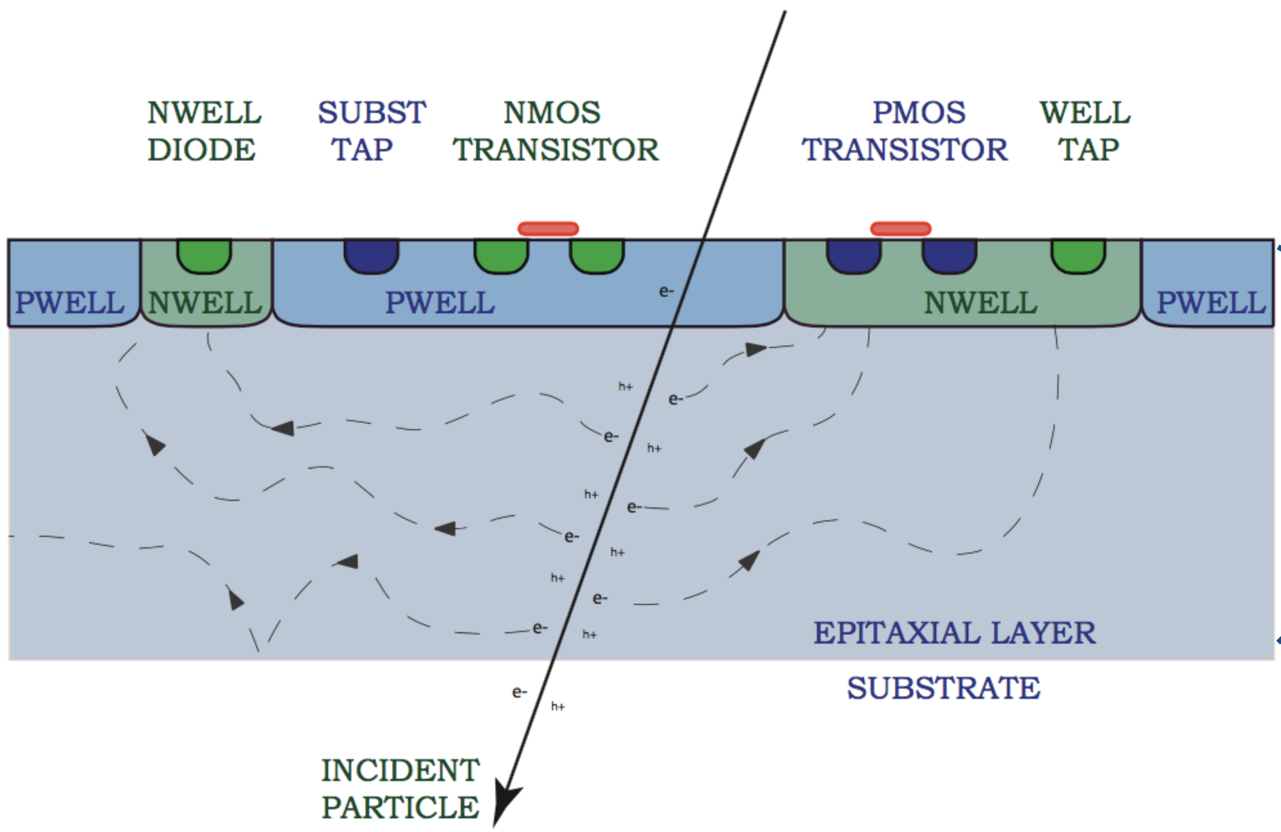
Pixel Layer 1, 92.5% Active

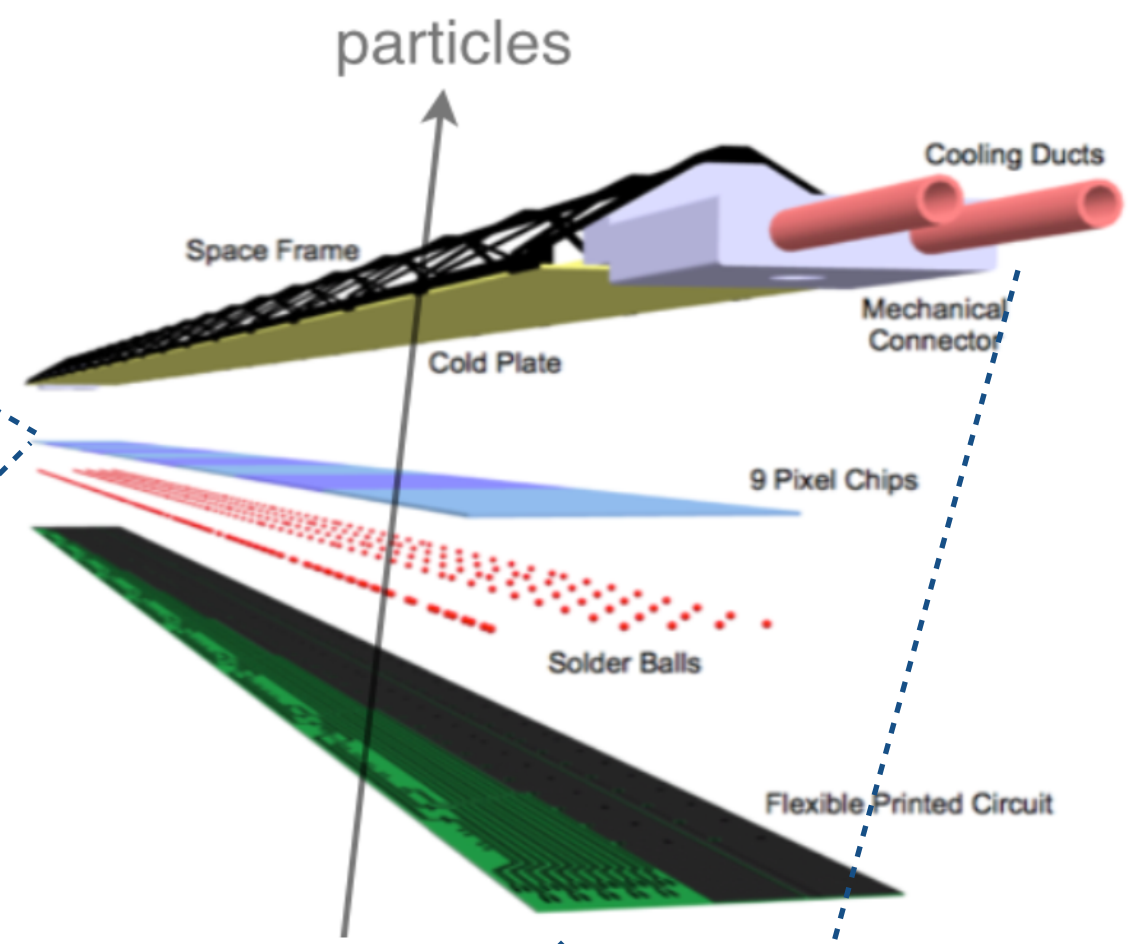


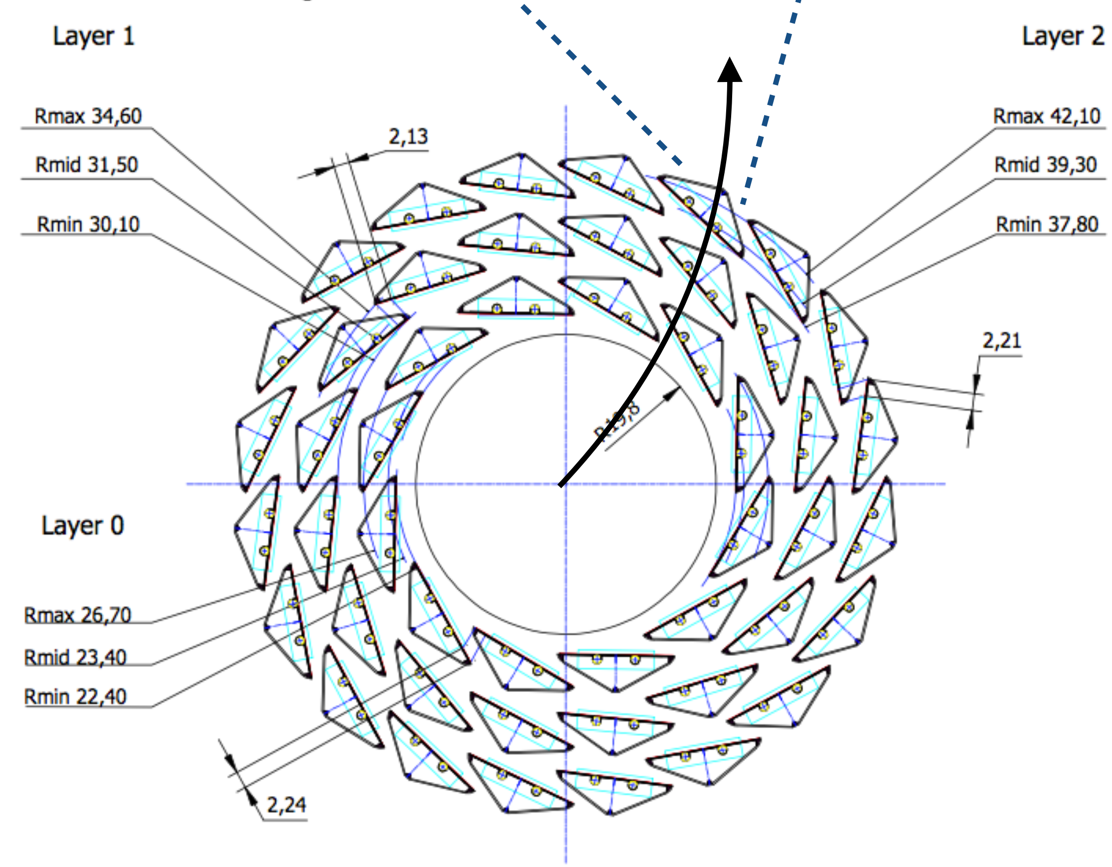
Pixel Layer 2, 72.5% Active

Station	Layer	radius (cm)	pitch (μm)	sensor length (cm)	depth (μm)	total thickness X_0%	area (m^2)
Pixel	1	2.4	50	0.425	200	1.3	0.034
Pixel	2	4.4	50	0.425	200	1.3	0.059
S0a	3	7.5	58	9.6	240	1.0	0.18

Tracking Option: MAPS sensors







Inner Silicon Concept:

Thin, fine pitch (<30 um), large efficiency

Optimizations for material thickness, ~0.3%/layer

Integration time: ~2-4 us

Goal:

Precision tracking & vertexing for b-jet identification and other tracking duties

Opportunity:

Reuse thin inner tracking layers during the EIC era

MAPS Geometry

from the pCDR:

Layer	radius (cm)	pitch (μm)	sensor length (μm)	depth (μm)	total thickness X_0%	length (cm)	area (m^2)
1	2.4	28	28	50	0.3	27	0.041
2	~4	28	28	50	0.3	27	~0.068
3	~6-15	28	28	50	0.3	~27-39	~0.102-0.368

3 layers will probably be needed to define the track position and curvature for a 2nd vertex reconstruction, can be done within the material cost of 1 VTX pixel layer

Similar inner layer positioning, just outside our beam pipe

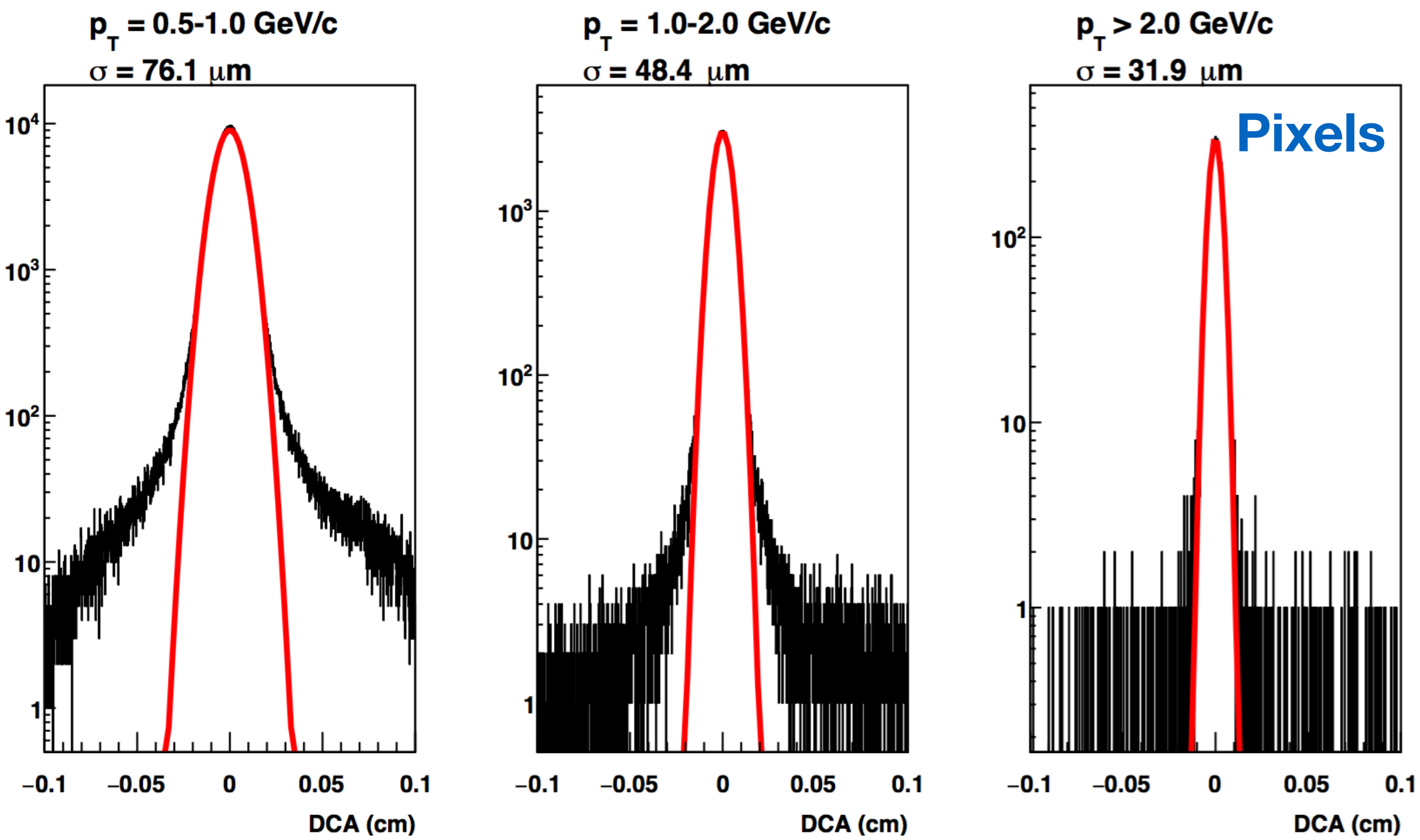
Outer staves could sit as far as 6 cm from the beam pipe before a longer than 27 cm ladder arrangement is needed—as dictated by vertex⊗eta coverage.

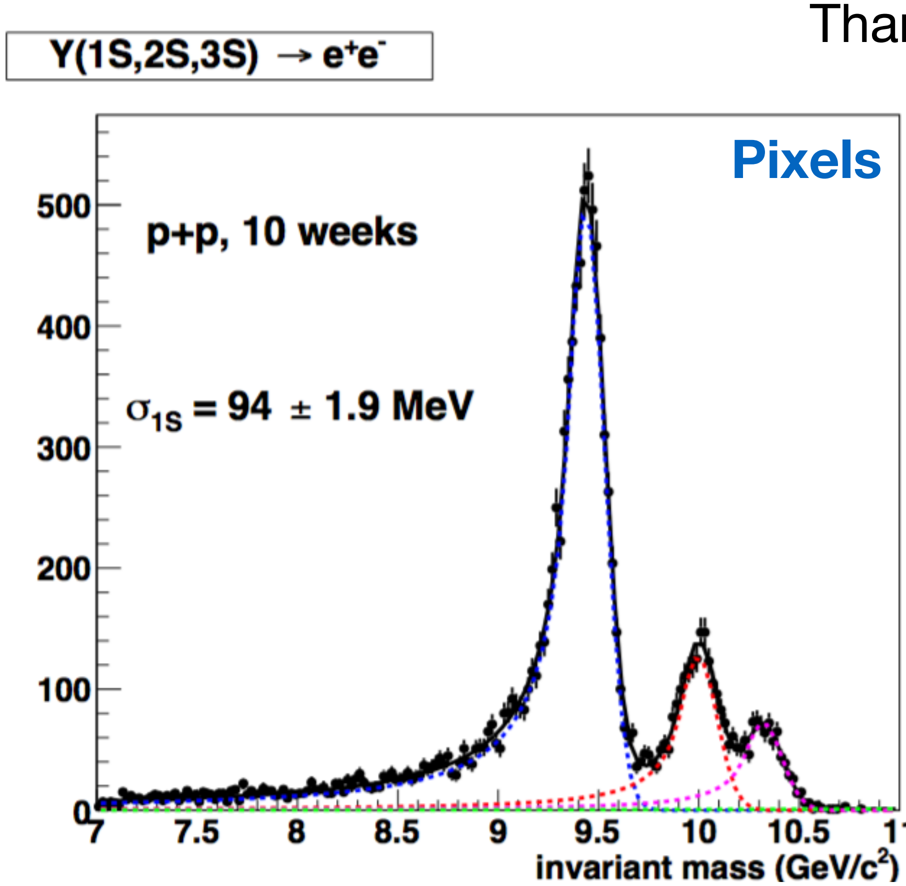
Optimizations between track position requirements and pattern recognition could force the outer layer out farther, depends on outer tracker design

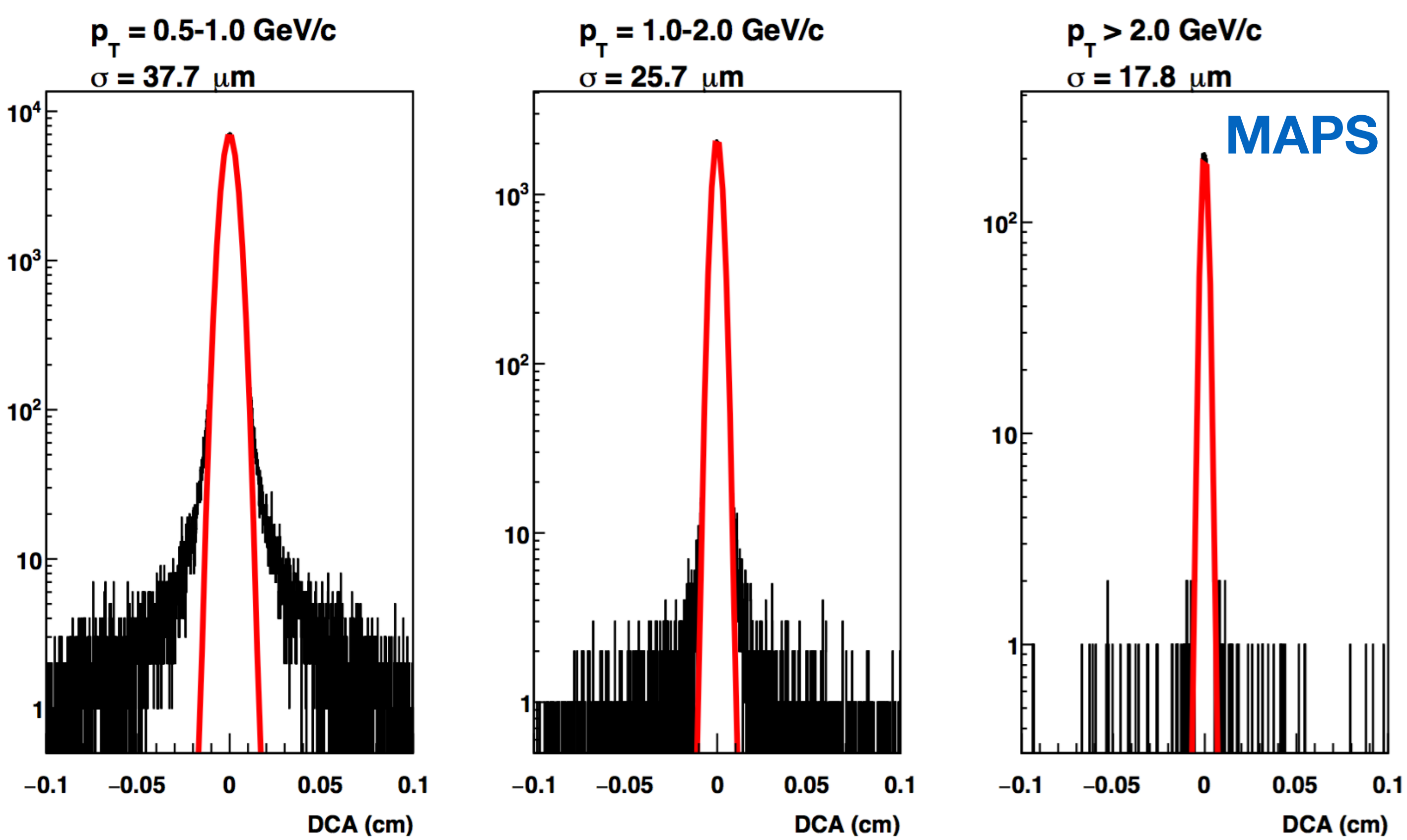
We started with the more compact (2.4,4,6) version…

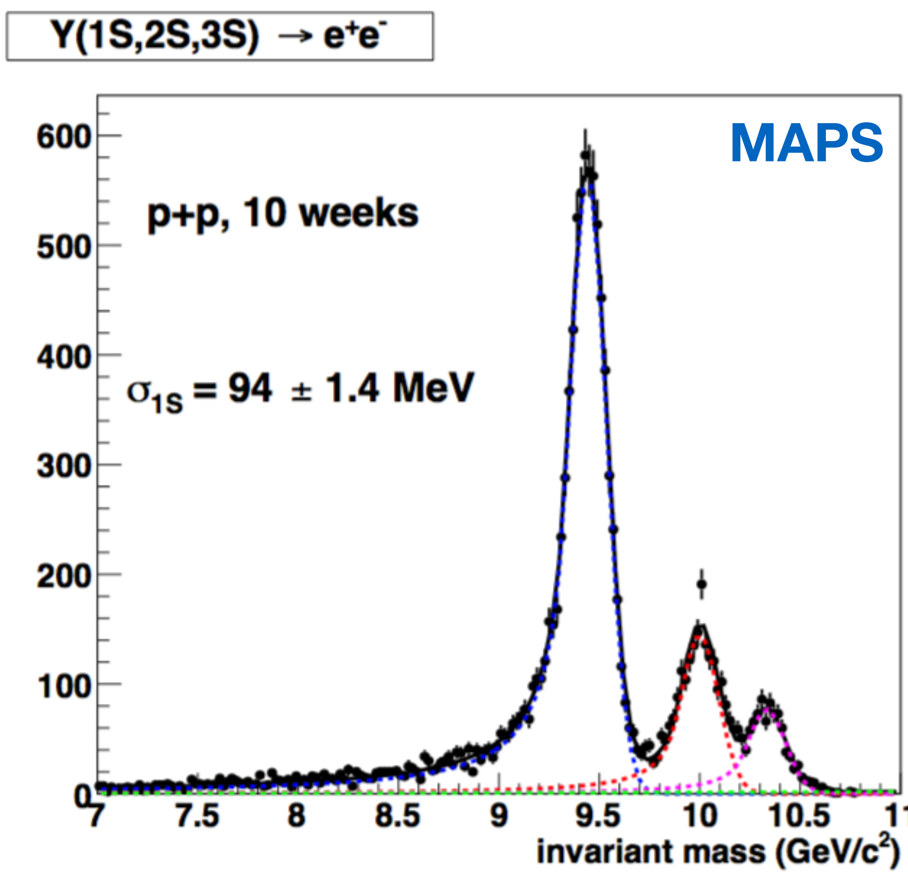
pCDR Performance Plots

Thanks TF!



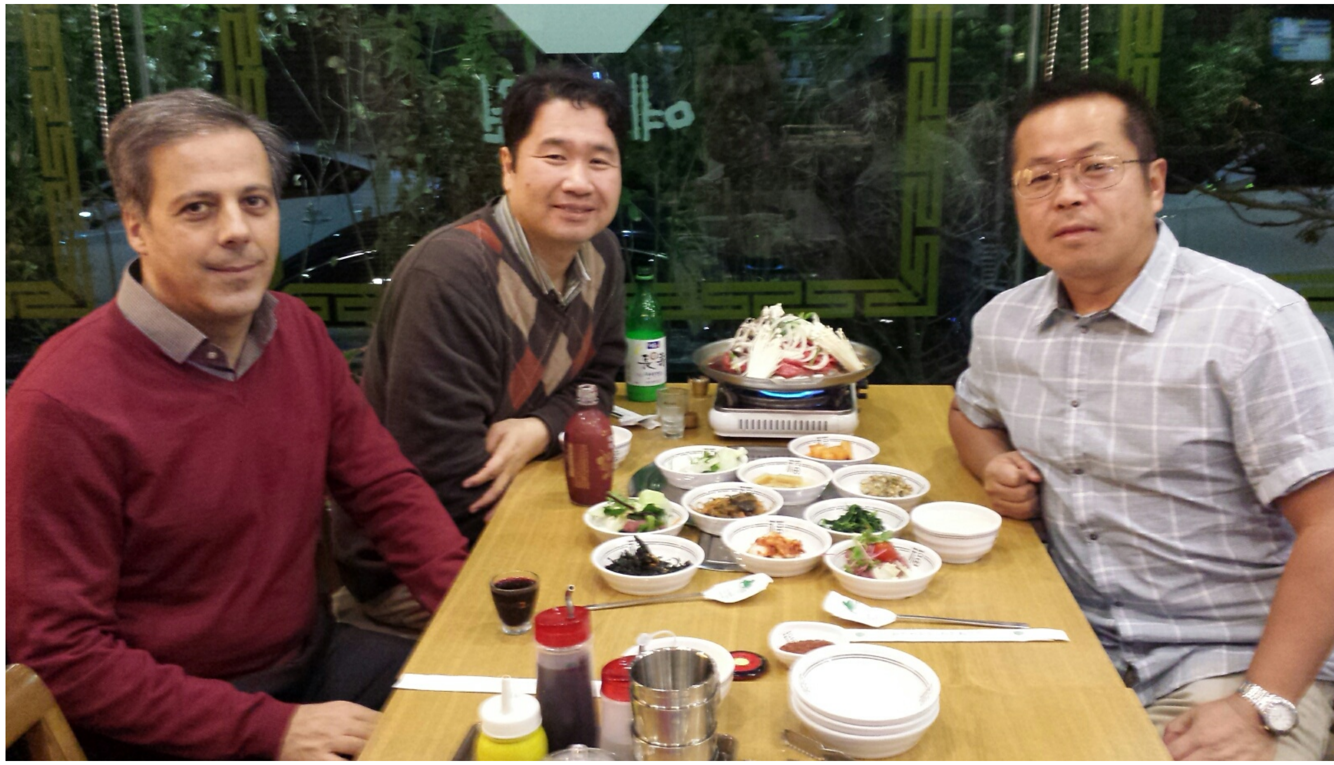






Making the MAPS a Reality

- Had good discussions with Luciano Musa and Yongil Kwon in Korea during K/J sPHENIX workshop
  - CERN will provide a few chips with readout cards "immediately" for sPHENIX/LANL R&D
  - For the final sPHENIX project, share the R&D cost with ALICE (~$2.5M) accordingly to the size of detectors (~$250K?)



- Plan to visit Berkeley(or CERN) to learn about the operation, and get help from them to start R&D at LANL

- Possible collaboration with Korea institutes to provide MAPS chips for sPHENIX inner pixel detectors
  - Korea funds:
    - MAPS chips
    - Production test, assembly etc.
    - A few $100K possible (new proposal)
  - LANL/US provide ROC/FEM
    - LANL LDRD/DR?
    - ~$1M ? (take advantage of ALICE ROC design etc., minimal R&D)

sPHENIX inner pixel detectors:
R = 2.5/4.0/6.0 cm
Z = +/-50cm
Area = 2*pi*R*Z
= 7,850 cm^2 = 0.8 m^2

Chip = 15mm x 30mm = 4.5 cm^2
7850/4.5 = 1750 chips
Wafer = 48 chips/$2K -> $73K

Pixel Reuse Pitfalls: Inefficiency

Simultaneous detection with Reused pixels for Track counting methods:

1 track = 33% loss

2 track = 55% loss

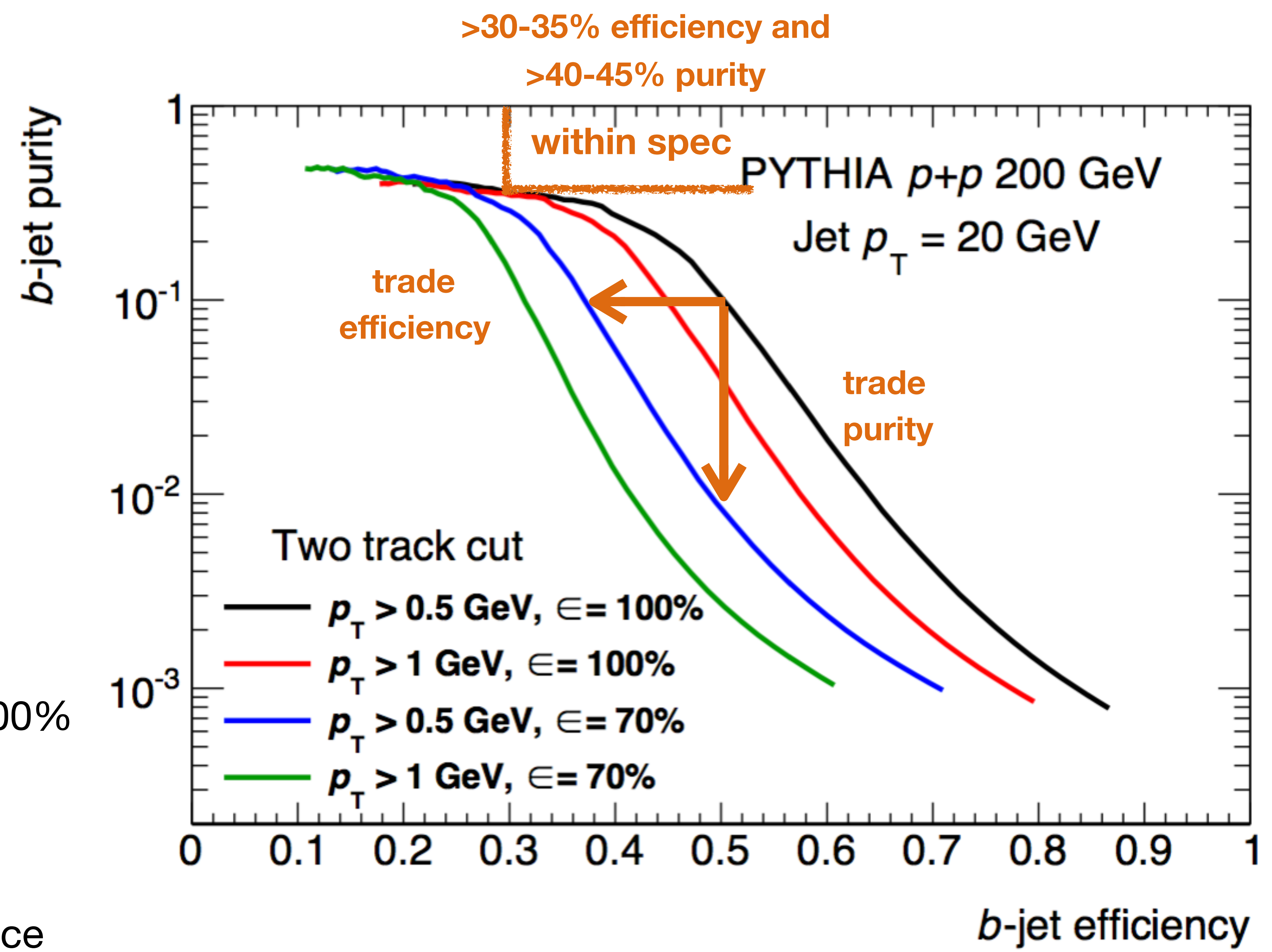
3 track = 70% loss

6-hit tracking + vertex fit will likely work for Upsilons, but not for b-jets

Not too far from spec with 100% efficiency

Could restore purity at lower efficiency, but then acceptance corrections will be come painful

Pretty clear: **Three hit methods will be completely lost, needed to get the largest purities!**



these efficiencies are not included in any sPHENIX b-jet RAA projections

MAPS efficiency for three layers, >99% active => <3% loss

Other Potential Pixel Reuse Pitfalls

Material thickness (1.3% per layer):

More clear now that with the strip outer layers the material in the inner layers isn't a driver on the Upsilon separation, we should repeat that with the TPC option

Long term evolution will still replace the pixels

One-dimensional optimization in pitch (50um x 425um):

VTX pixels were designed around a DCA-based analysis

Two track intersection probabilities needed for 2nd vertex reconstruction need to be understood

Can the VTX pixels perform the 2nd vertex reconstruction at all?

DAQ Rate:

VTX pixel test saw 14 kHz at 60% live time, somewhat under our 15 kHz ~90% live time readout spec

New hardware could design in the full readout bandwidth

Not sure where the next bottleneck would be, more than a small gain?

Limited TPC integration flexibility:

A finite surface area of VTX pixels is available, we can cover 2.4 cm and 4.4 cm

TPC based tracking starts no closer than 30 cm

4.4 cm to 30 cm is a long jump to make

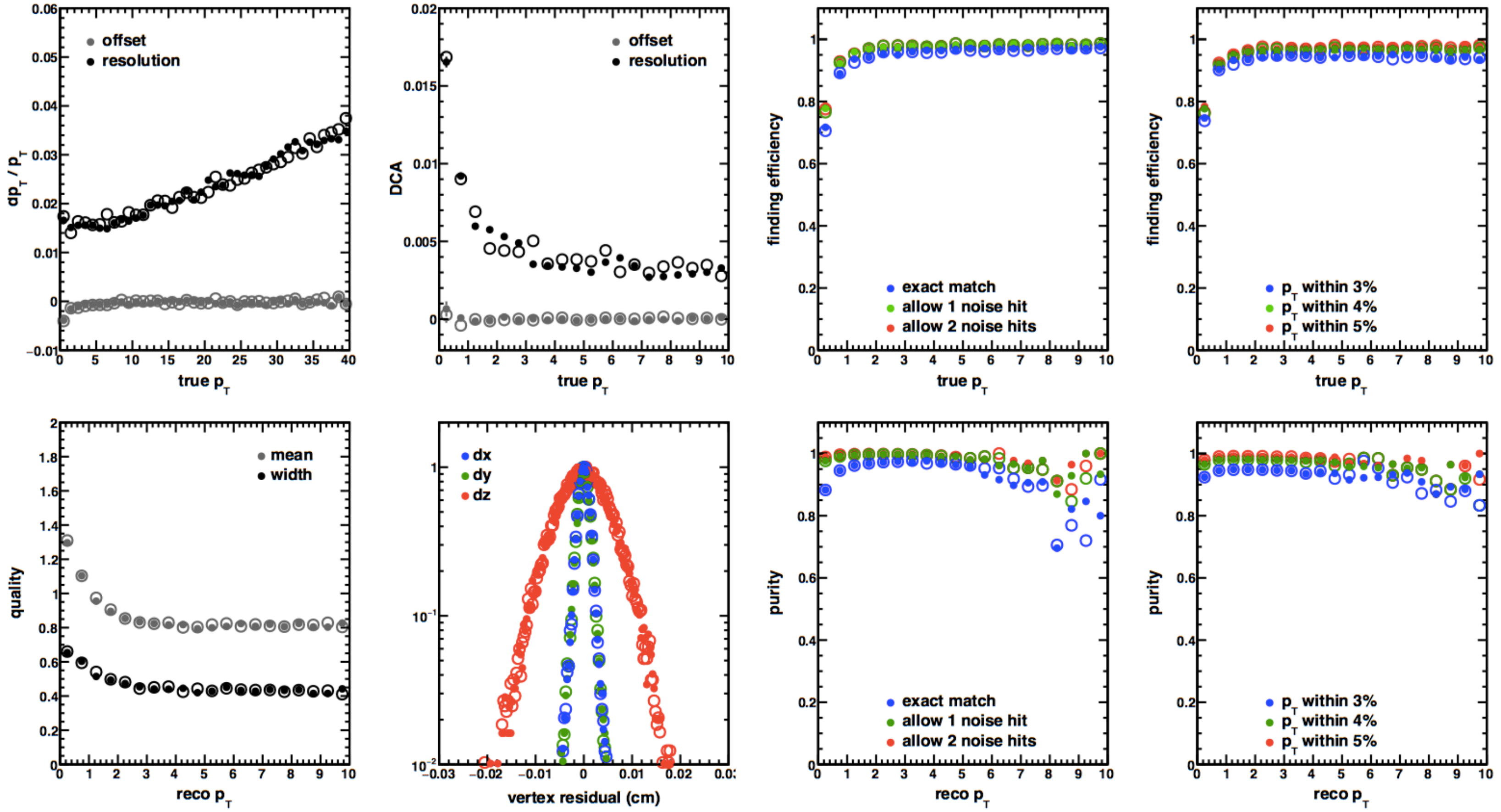
We may need a tracking layer between 4.4 and 30 cm to break ambiguities in the tracking

How to Proceed?

(1) Finalize the detector requirements needed to extract the b-jet physics
+ utilize CMS-inspired requirements (manpower would suggest this option)
Suggested numbers: 3D IP resolution of 15-30 um
Single particle efficiency of 95%
Fake rate <2% 1-10 GeV/c

(2) Develop steering macros with all 4 detector combinations
(VTXP vs MAPS) x (Strips vs TPC) using simple geometries (cylinders)
+ start the optimization process on each for the basic parameters

with 45-60 minute turn around time…



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(3) Further develop the tracker software to deal with more complex geometries and tasks
(real-world Kalman, primary tracking through to the vertex, Rave, etc)

(4) Further develop b-jet identification to explore 2nd vertex methods

Backup Slides

Open Questions for the Effort

What are the quantitative **tracking requirements for b-physics** utilizing all 3 proposed channels?

+ define a single particle tracking efficiency requirement
+ define a DCA precision needed for 2nd vertex id
+ define a b-jet purity and efficiency that is the minimum need

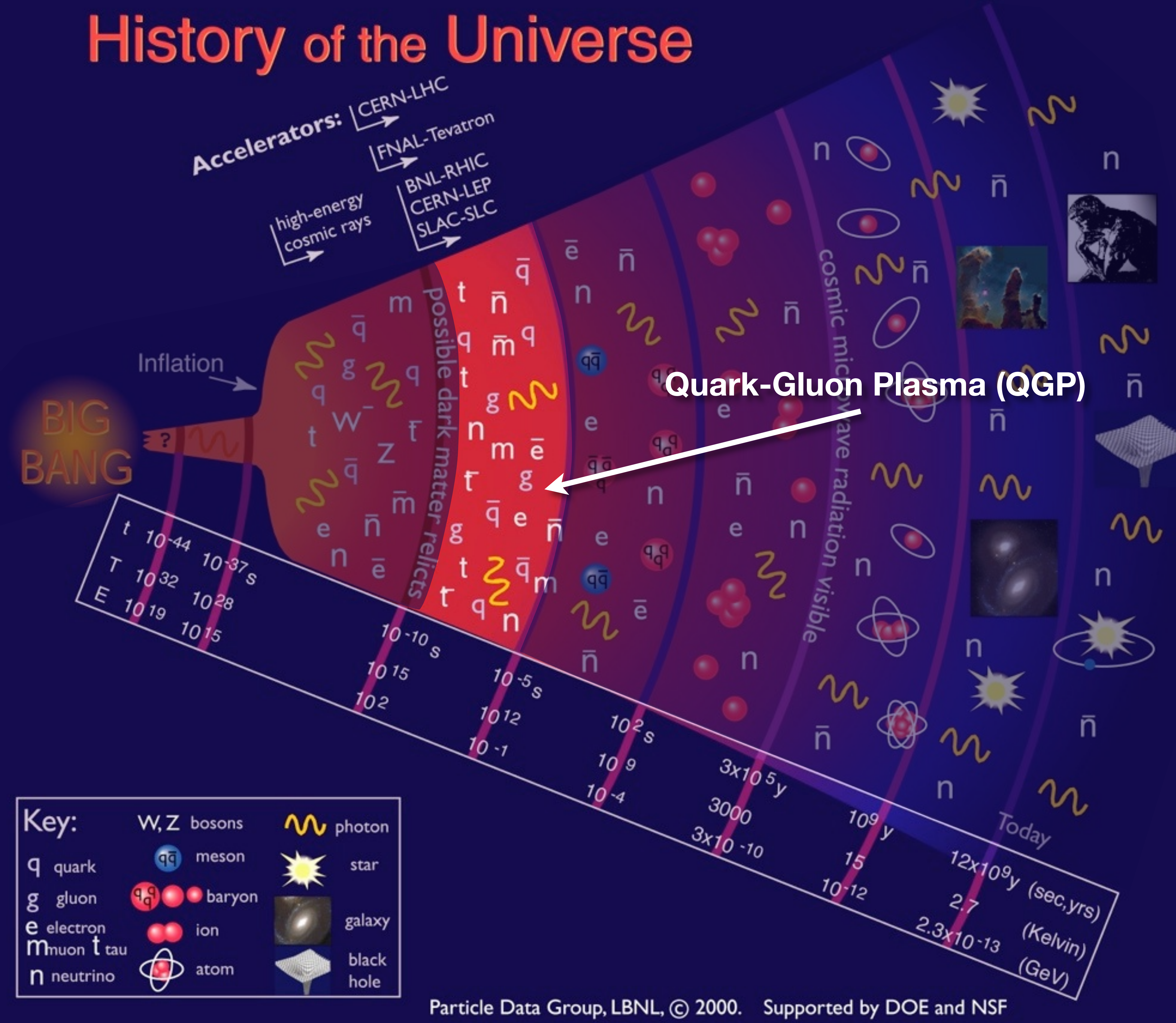
We've been using a **fake track requirement**: <2% or so below 10 GeV/c as an indication things will work. Why isn't this in the requirement list?

Can the TPC measure 30-40 GeV/c fragments within spec?

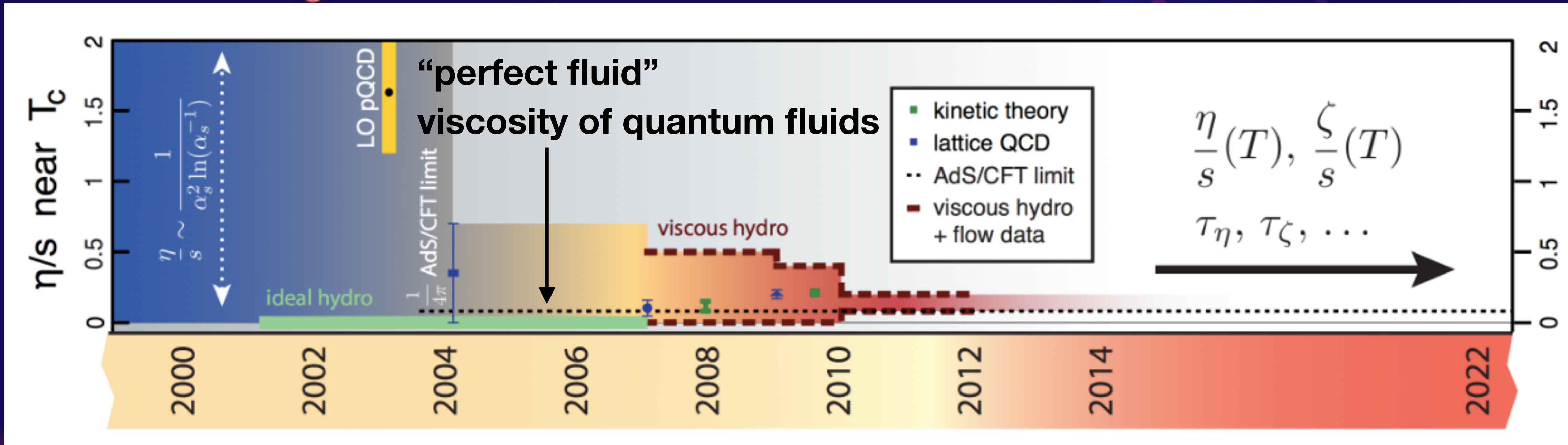
Can we live with the TPC ~40 μsec integration time?

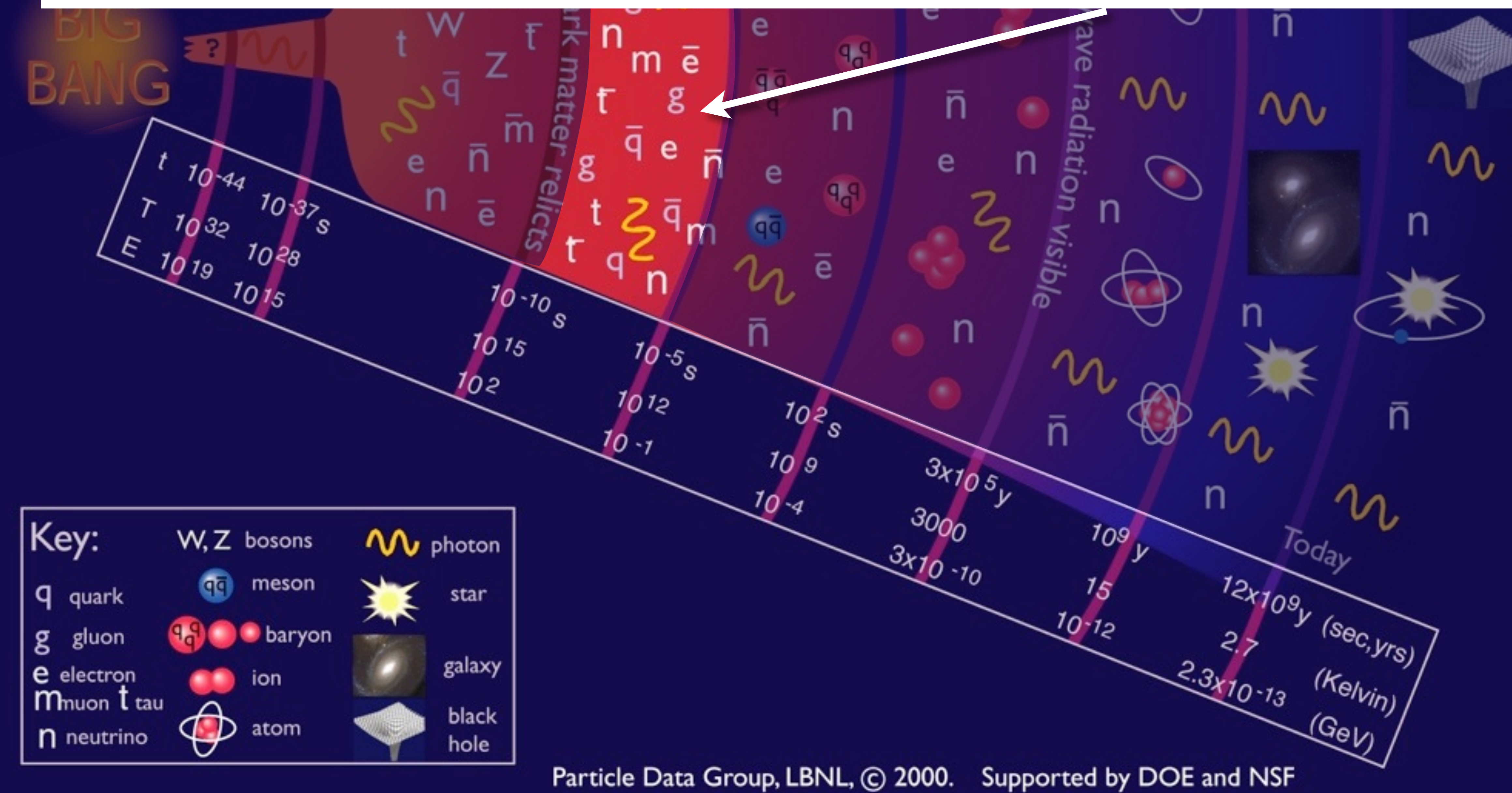
Can we live with the MAPS 2-4 μsec integration time?
Could we live with just two inner MAPS layers?

sPHENIX proposal

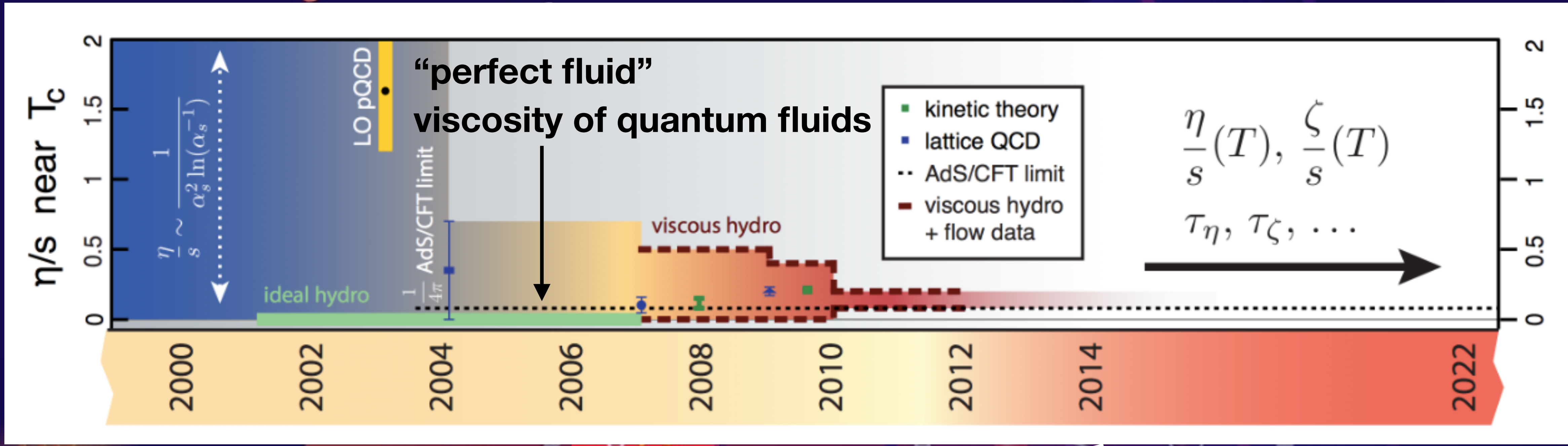

History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
Quark-Gluon Plasma (QGP)
t 10^{-44} 10^{-37} s 10^{-10} s 10^{-5} s 10^{2} s $3\text{x}10^{5}$ y 10^{9} y $12\text{x}10^{9}$ y (sec,yrs)
T 10^{32} 10^{28} 10^{15} 10^{12} 10^{9} 3000 15 2.7 (Kelvin)
E 10^{19} 10^{15} 10^{2} 10^{-1} 10^{-4} $3\text{x}10^{-10}$ 10^{-12} $2.3\text{x}10^{-13}$ (GeV)
Today
Key:
q quark
g gluon
e electron
m muon
t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

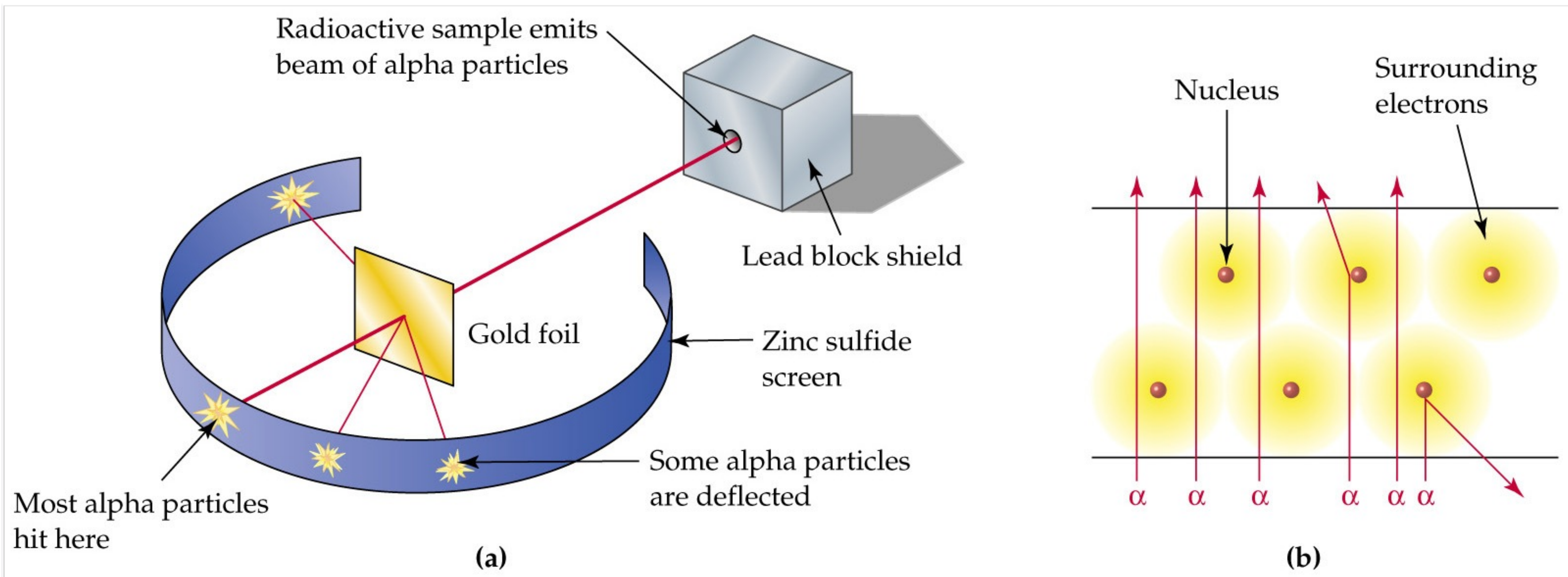
History of the Universe





History of the Universe





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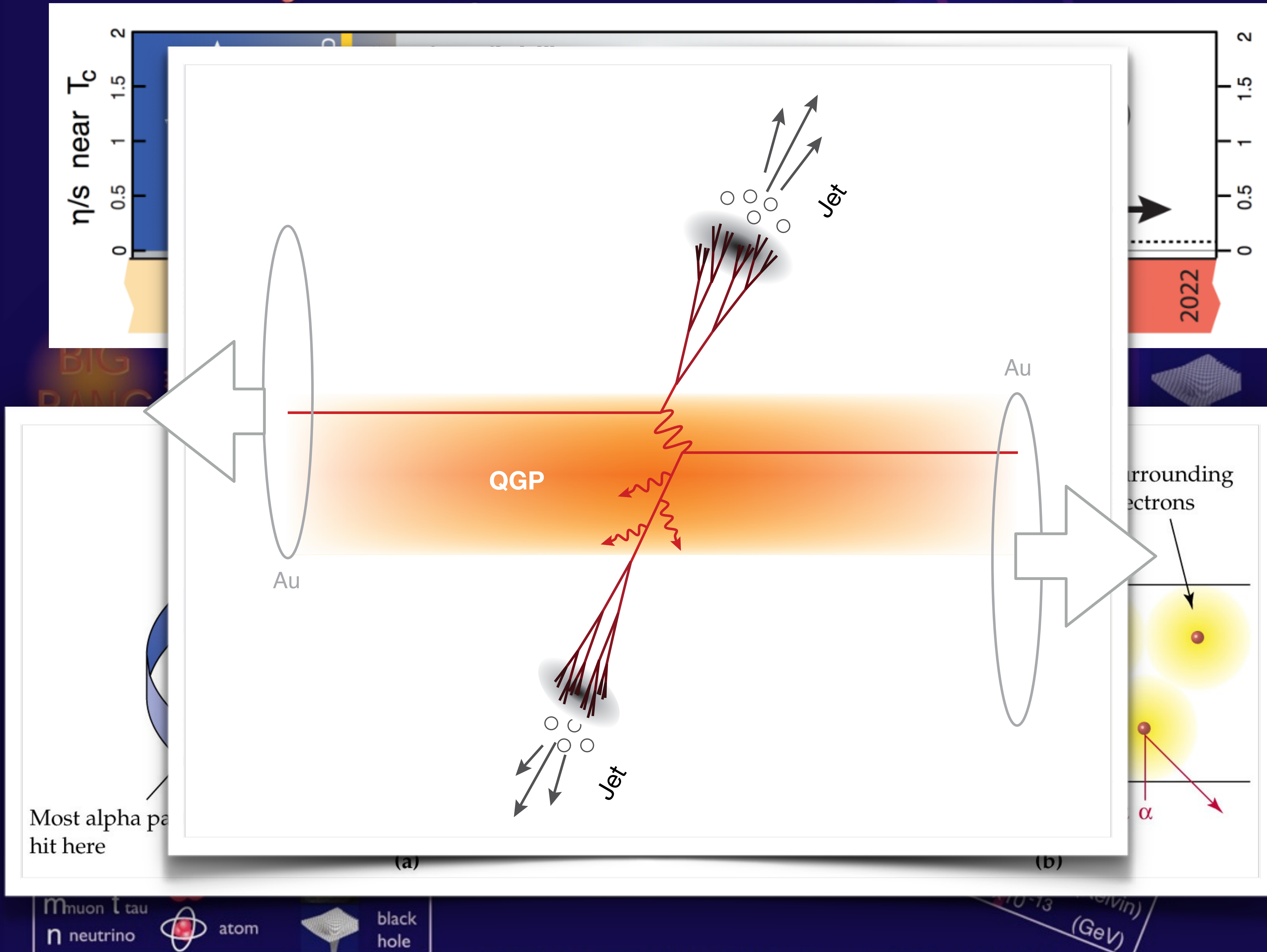

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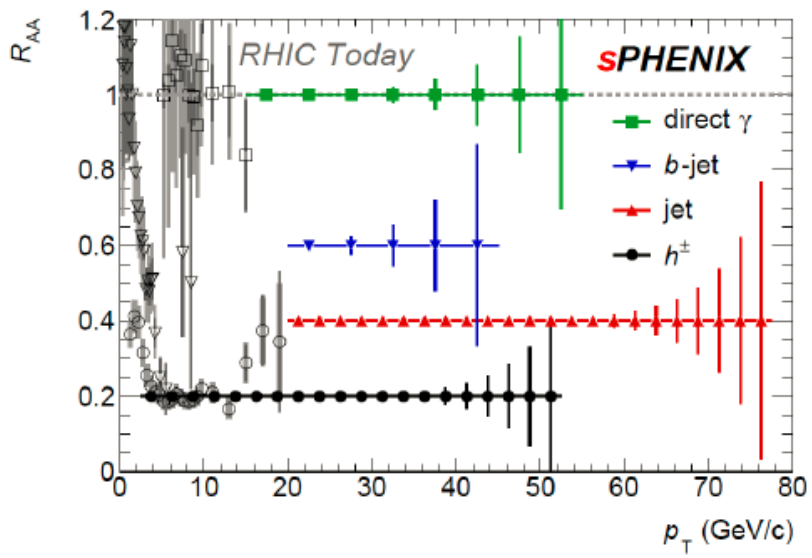
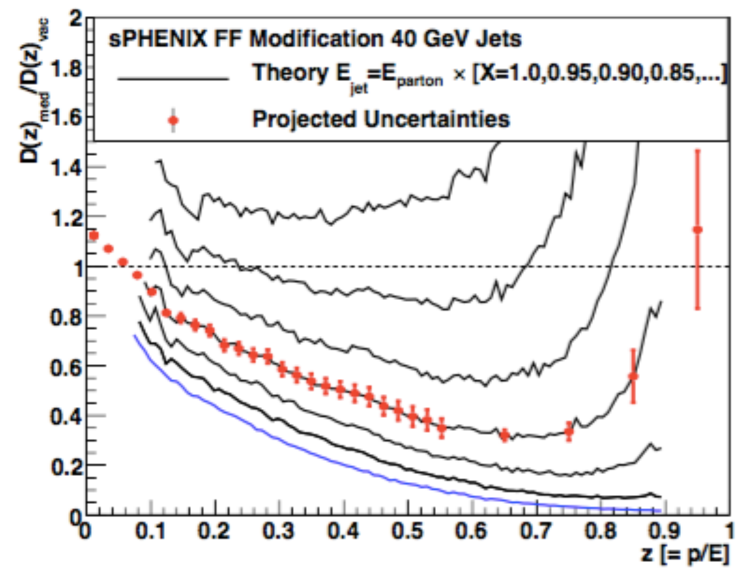
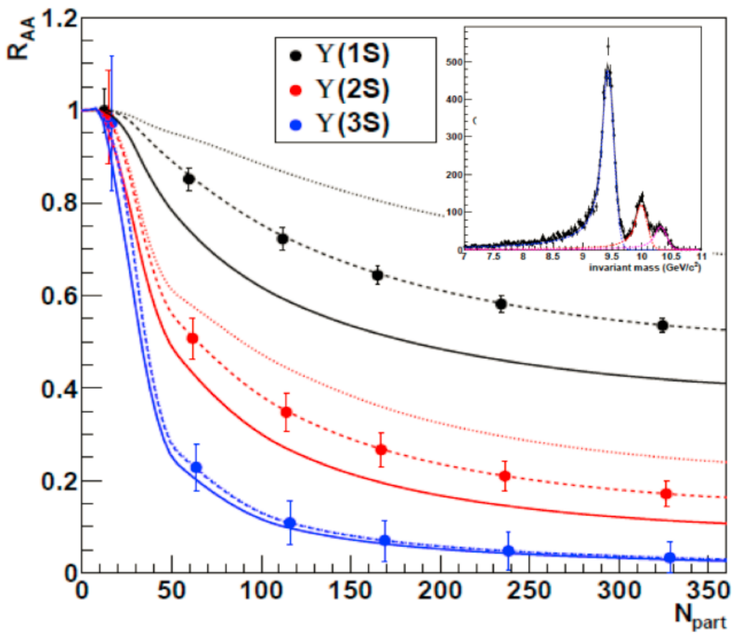
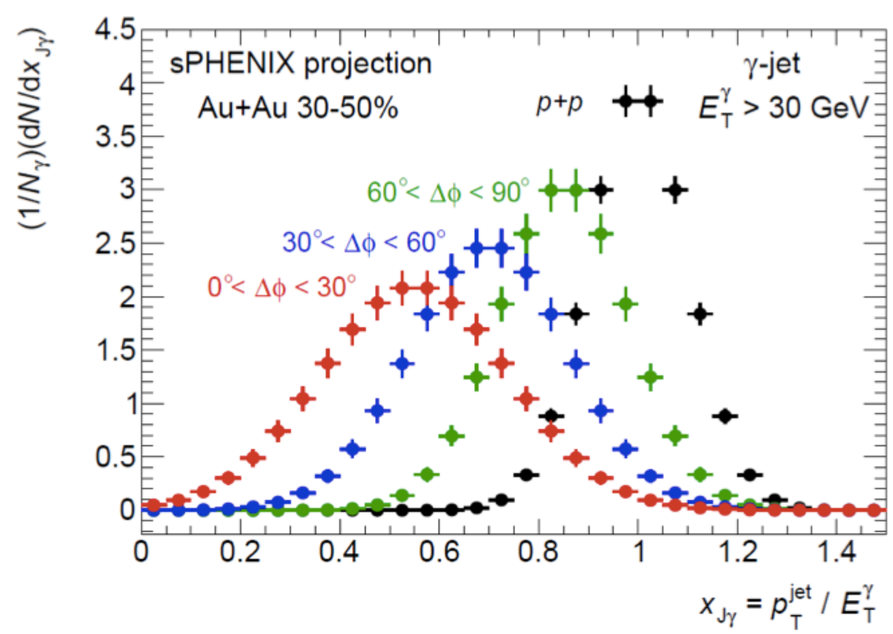
sPHENIX proposal

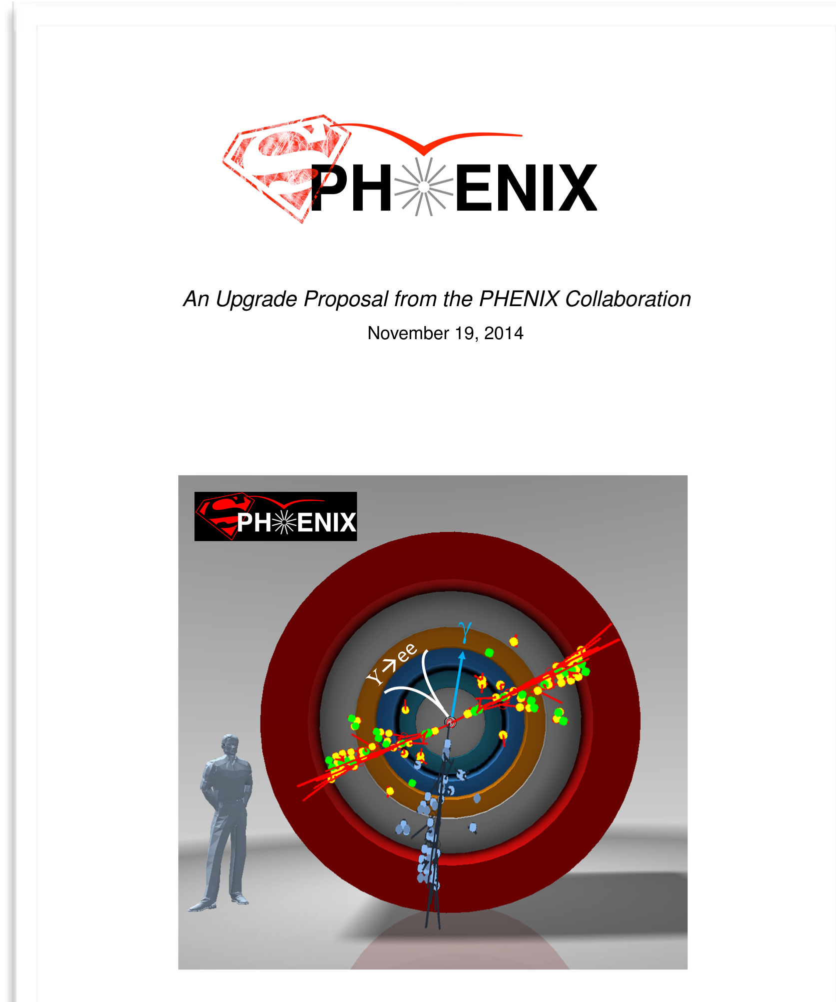
Jets and Upsilons…











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Goal: study of QGP structure over a range of length scales and temperatures with **hard-scattered probes**

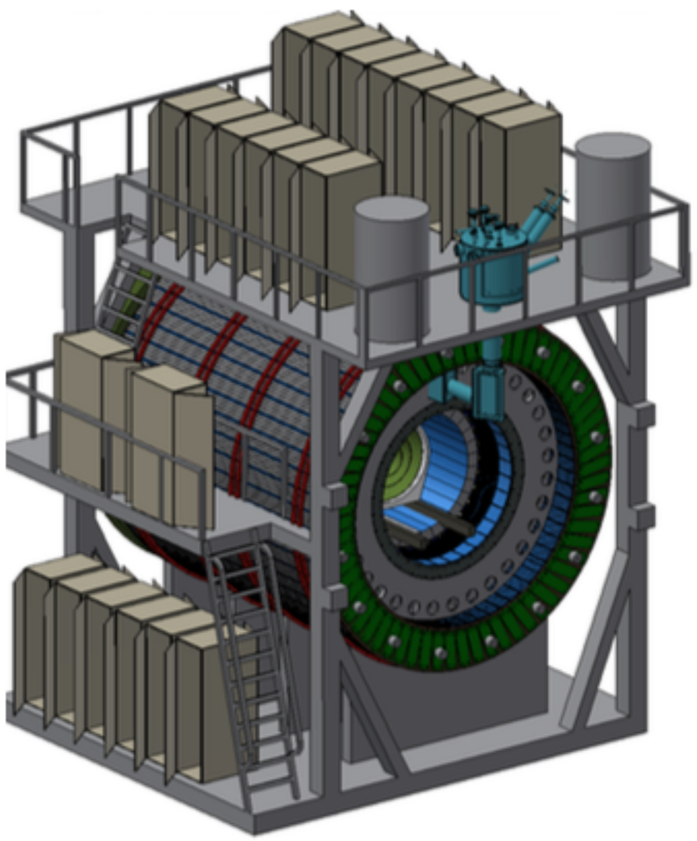
"[sPHENIX] presented a compelling physics program."
~ sPHENIX Science Review Committee

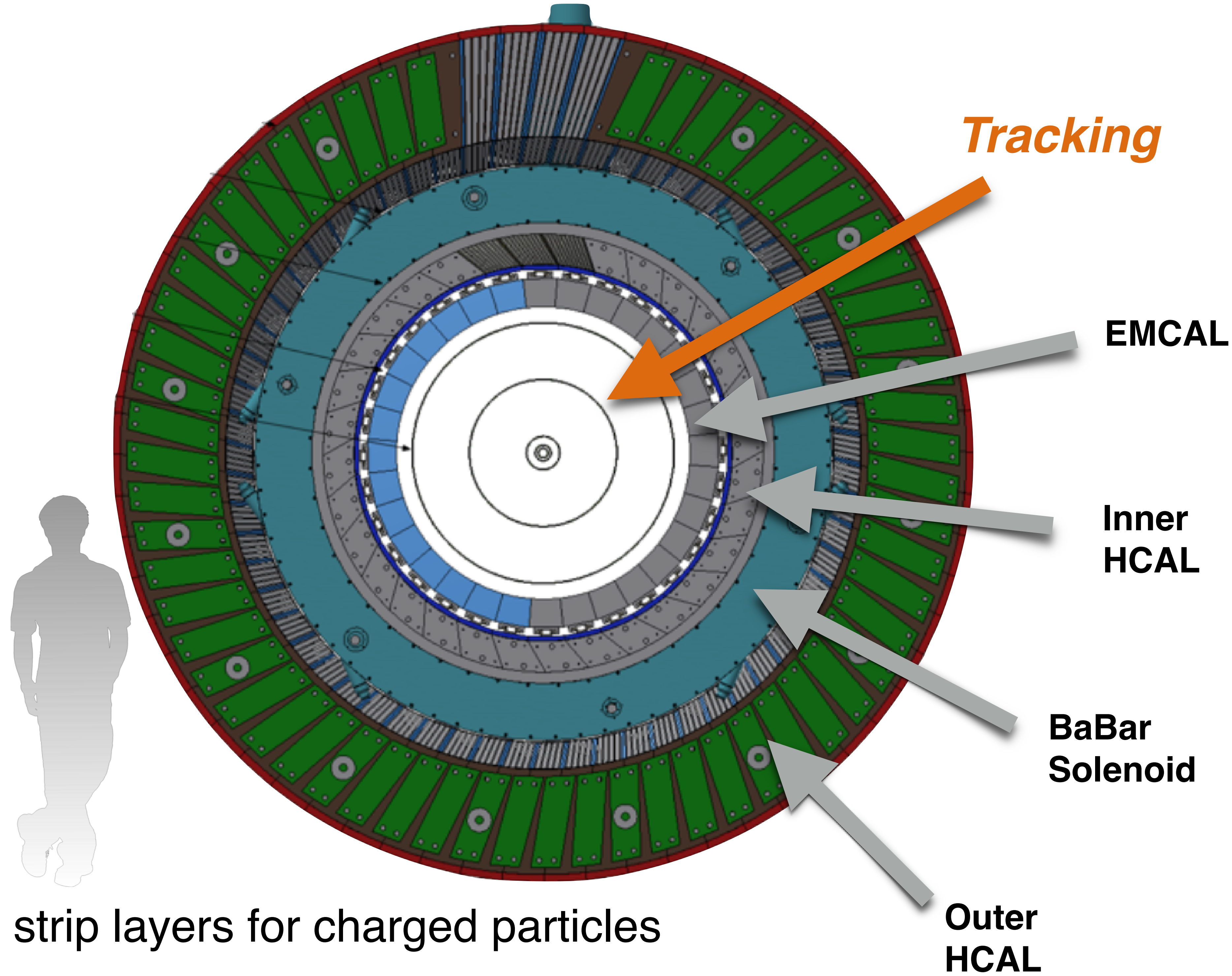
sPHENIX highlighted in Hot QCD Long Range Plan

Updates include:

- jet trigger estimates
- b-tagged jets
- updated luminosity proj.
- jet+X observables
- tracking performance
- etc…

sPHENIX Detector Design





Conceptual Design:

- $-1.1 < \eta < +1.1$, $\Delta\phi = 2\pi$
- BaBar solenoid, 1.5 T
- Reconfigured pixel + new strip layers for charged particles
- EMCal to measure photons & electrons
- Inner+Outer HCAL to complete jet measurement
- High rate DAQ, 15 kHz

sPHENIX excels: Upsilon Channel

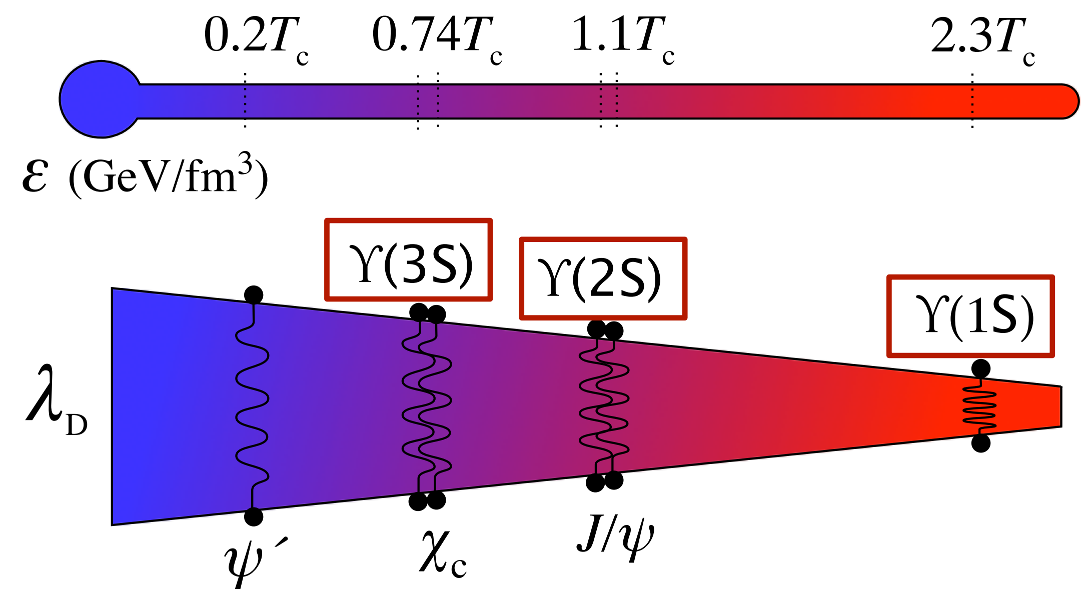
RHIC vs. LHC collision energy:

(1)30% temperature reduction

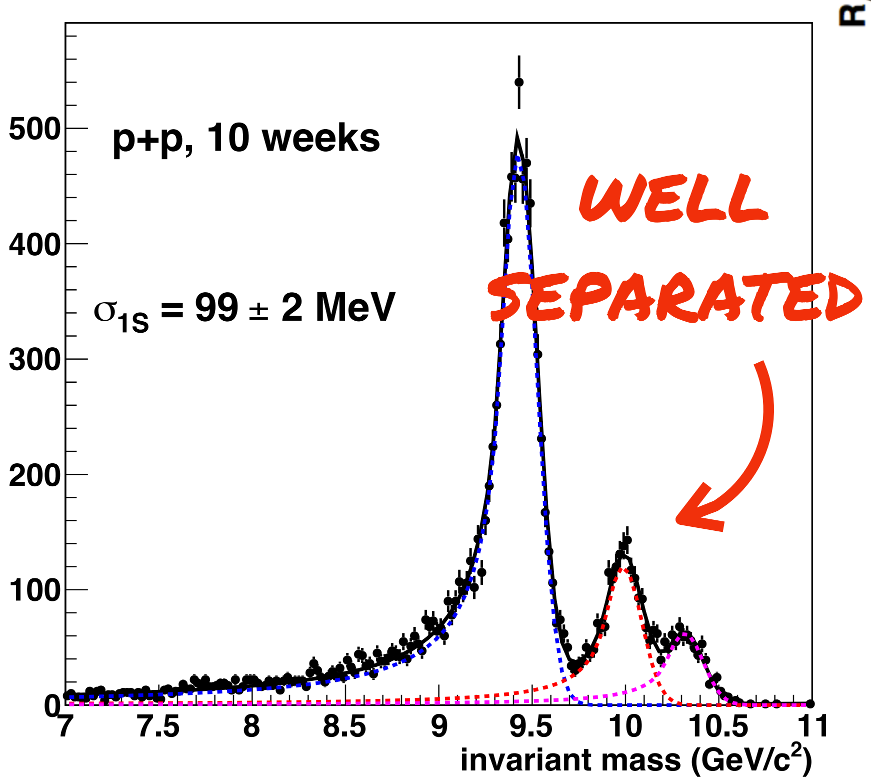
(2)negligible recombination rates

(3)different mixture CNM effects

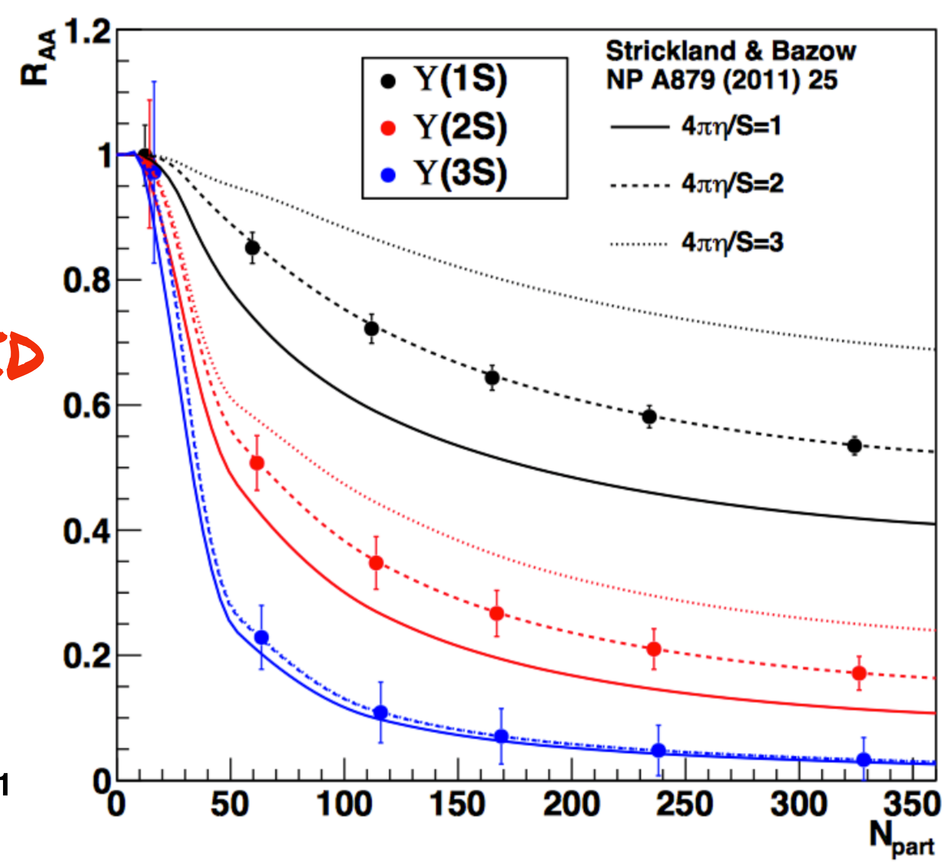
(4)transverse momentum dependent suppression



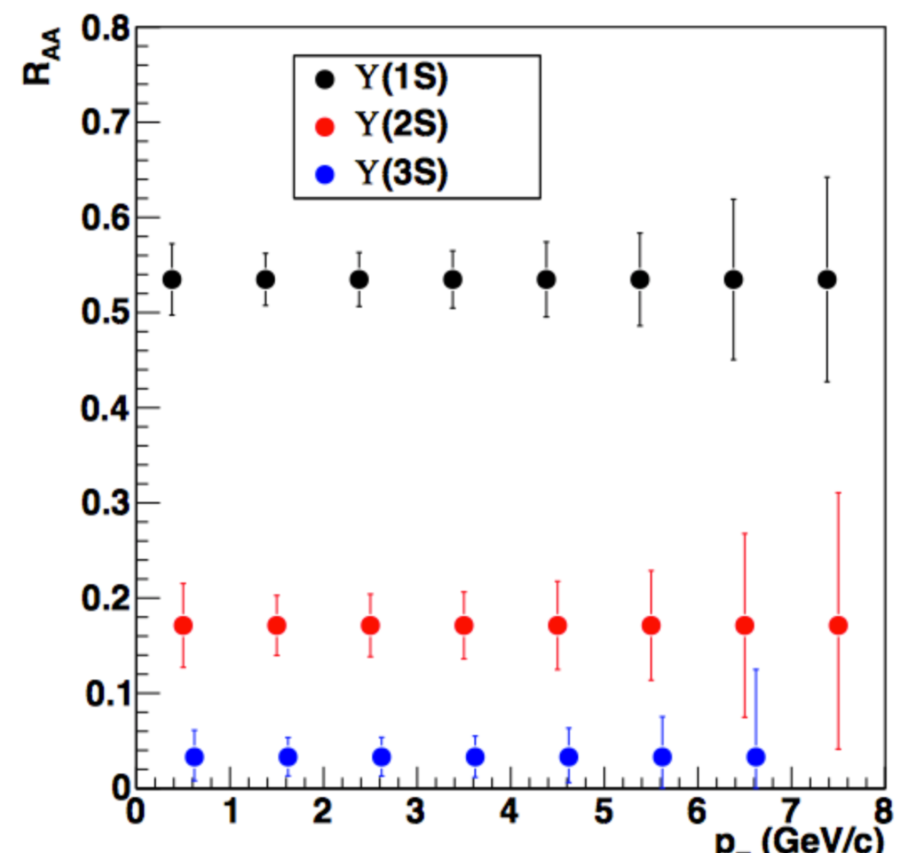
$$\Upsilon \rightarrow e^- \, e^+$$



centrality dependence



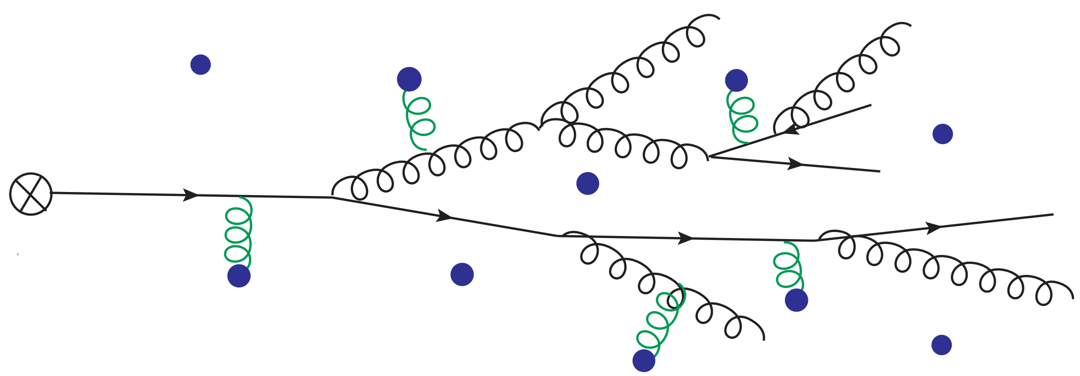
momentum dependence

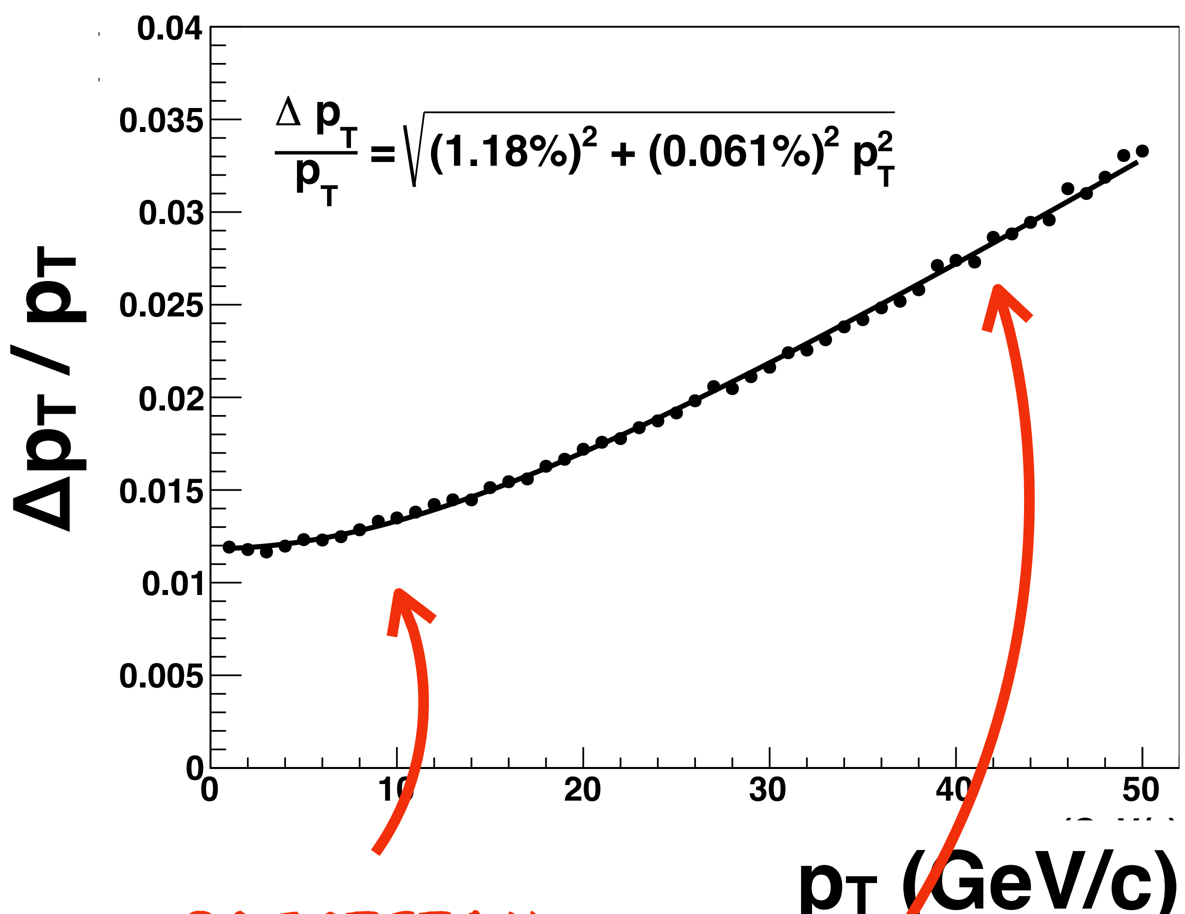


+ comparable CNM measurements in p+A

sPHENIX excels: Jet Fragmentation

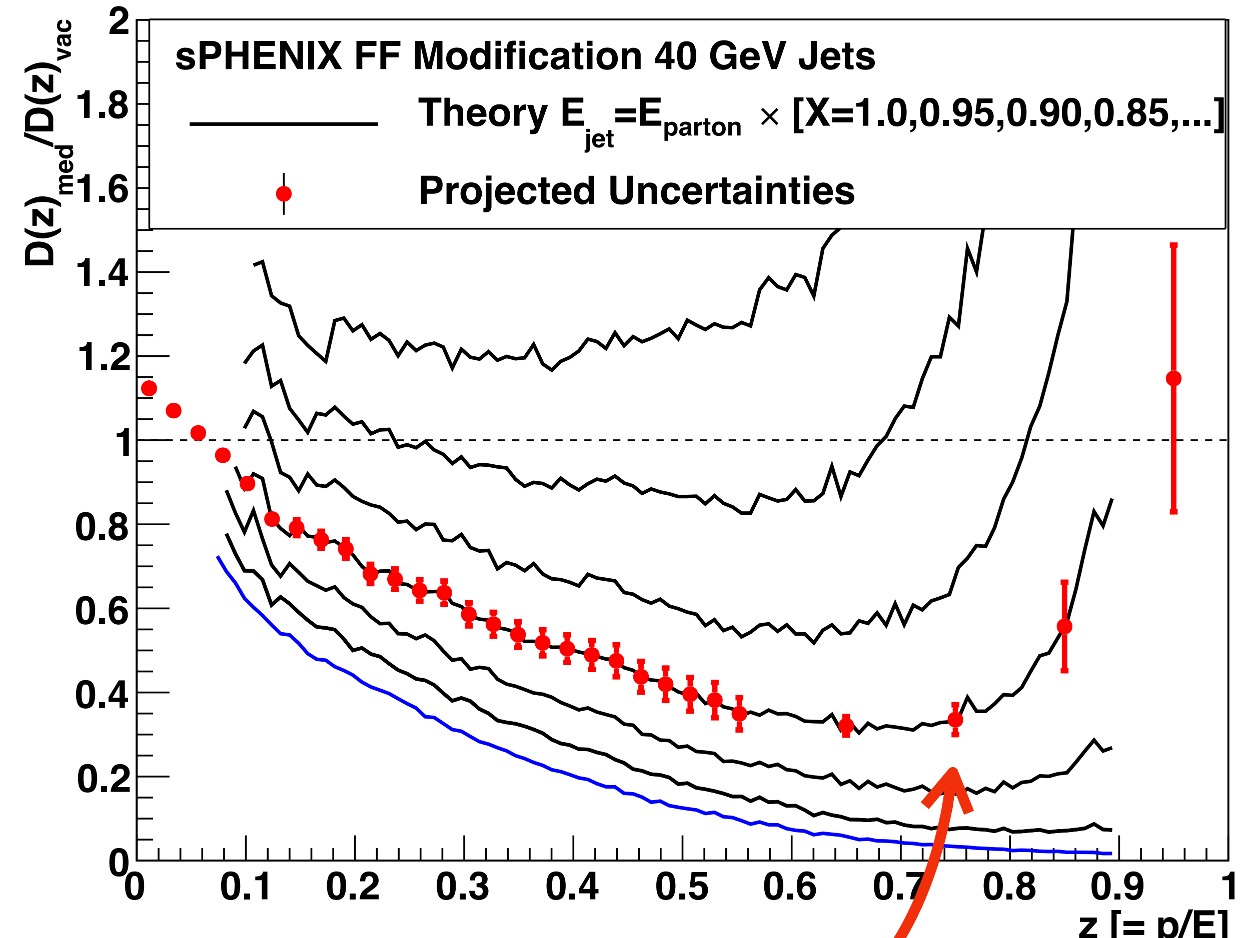
Jet fragmentation substructure at large angles & low momentum





PRECISION FOR UPSILON

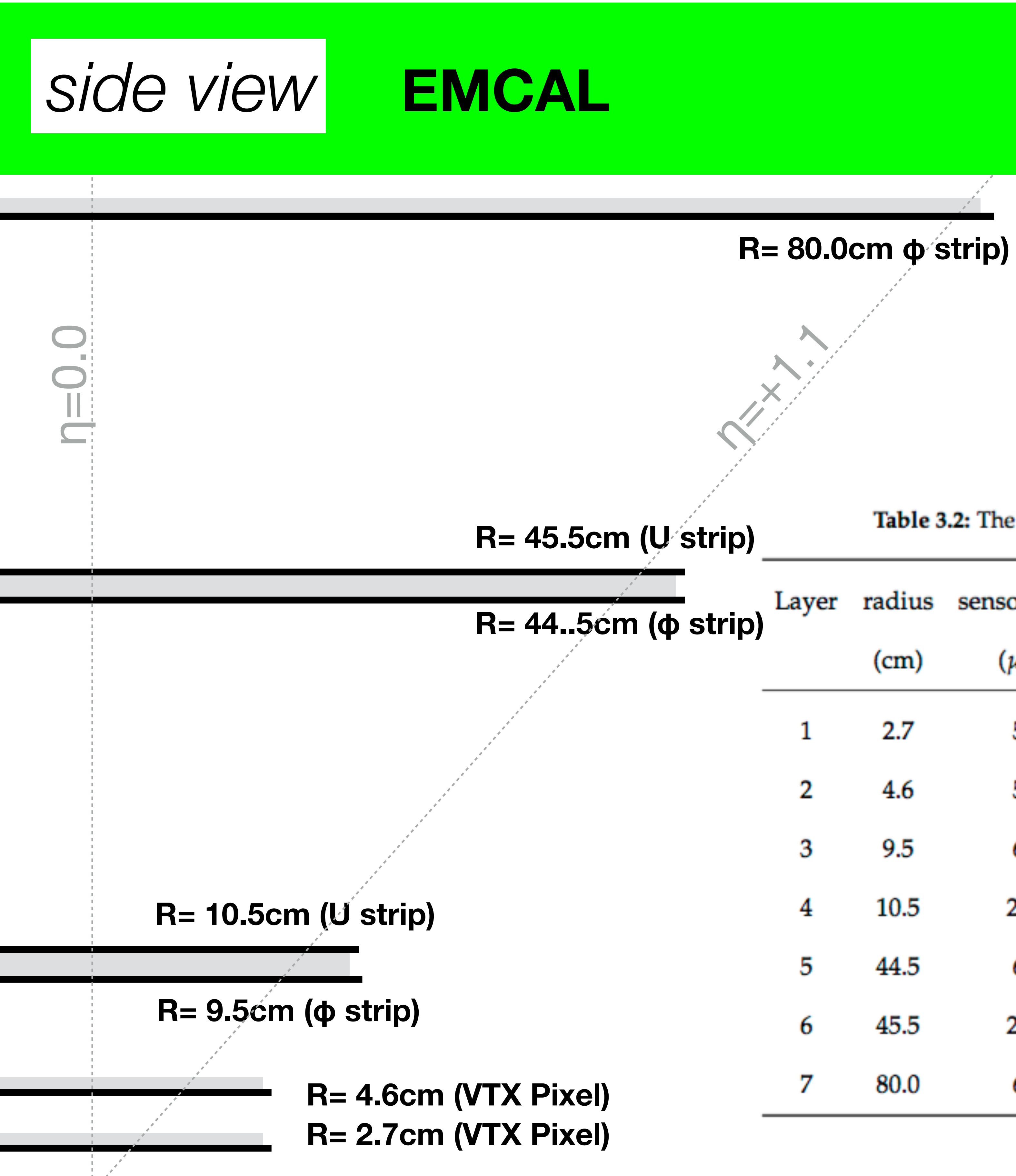
...AND FOR D(Z)



LARGE STATS

Precision measurements of energy loss in and out of jet cone

Hybrid Silicon Tracking Option



sPHENIX conceptual design

Provides 100 MeV/c^2 mass resolution for Upsilon states

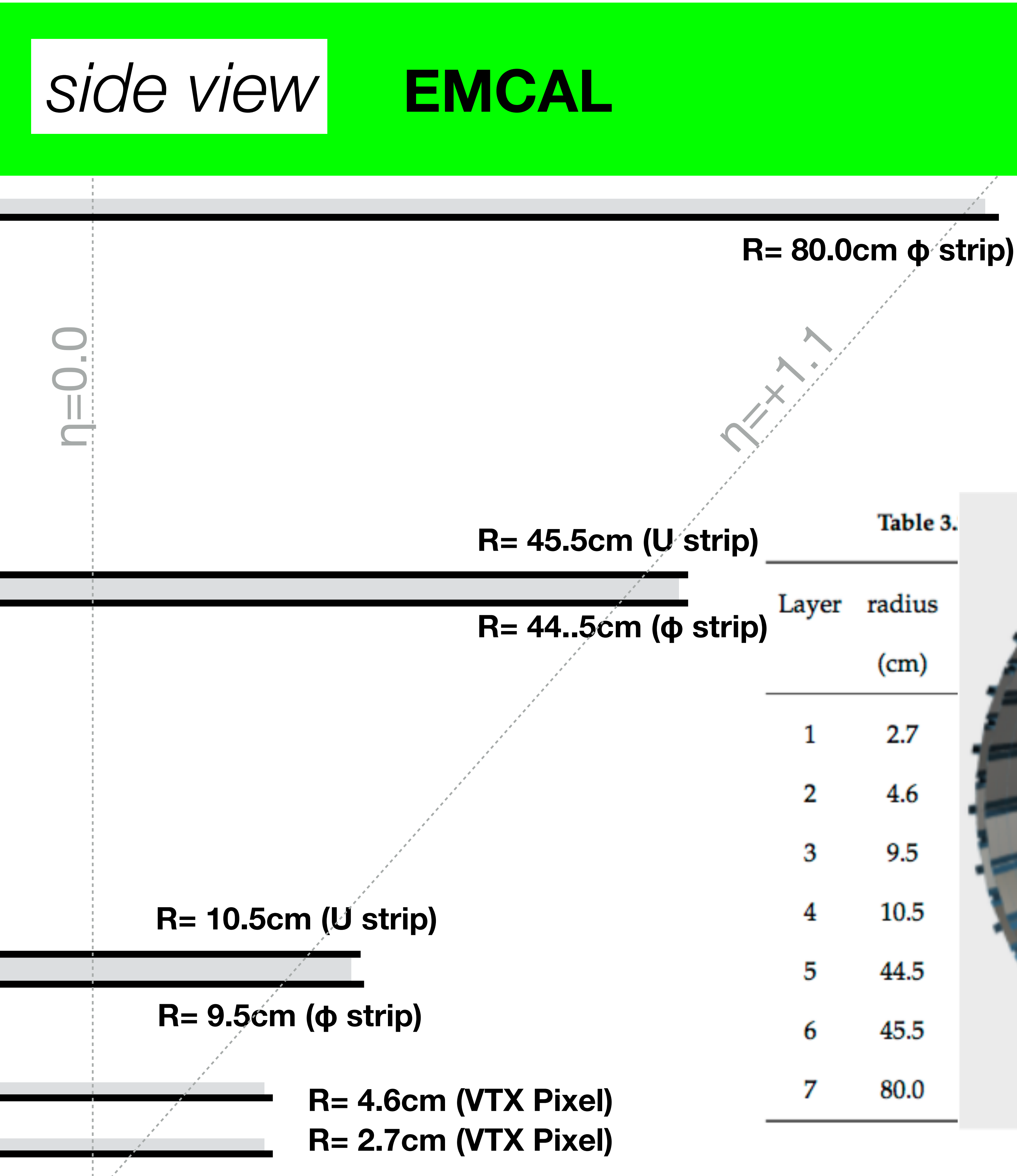
Technical design R&D ongoing

Optimizations: smaller mass, smaller area

Table 3.2: The parameters of the reference configuration tracking layers.

Layer	radius (cm)	sensor pitch (μm)	sensor length (mm)	sensor depth (μm)	total thickness % X_0	area m^2
1	2.7	50	0.425	200	1.3	0.034
2	4.6	50	0.425	200	1.3	0.059
3	9.5	60	8	320	1.35	0.152
4	10.5	240	2	320	1.35	0.185
5	44.5	60	8	320	1	3.3
6	45.5	240	2	320	1	3.5
7	80.0	60	8	320	2	10.8

Hybrid Silicon Tracking Option



sPHENIX conceptual design

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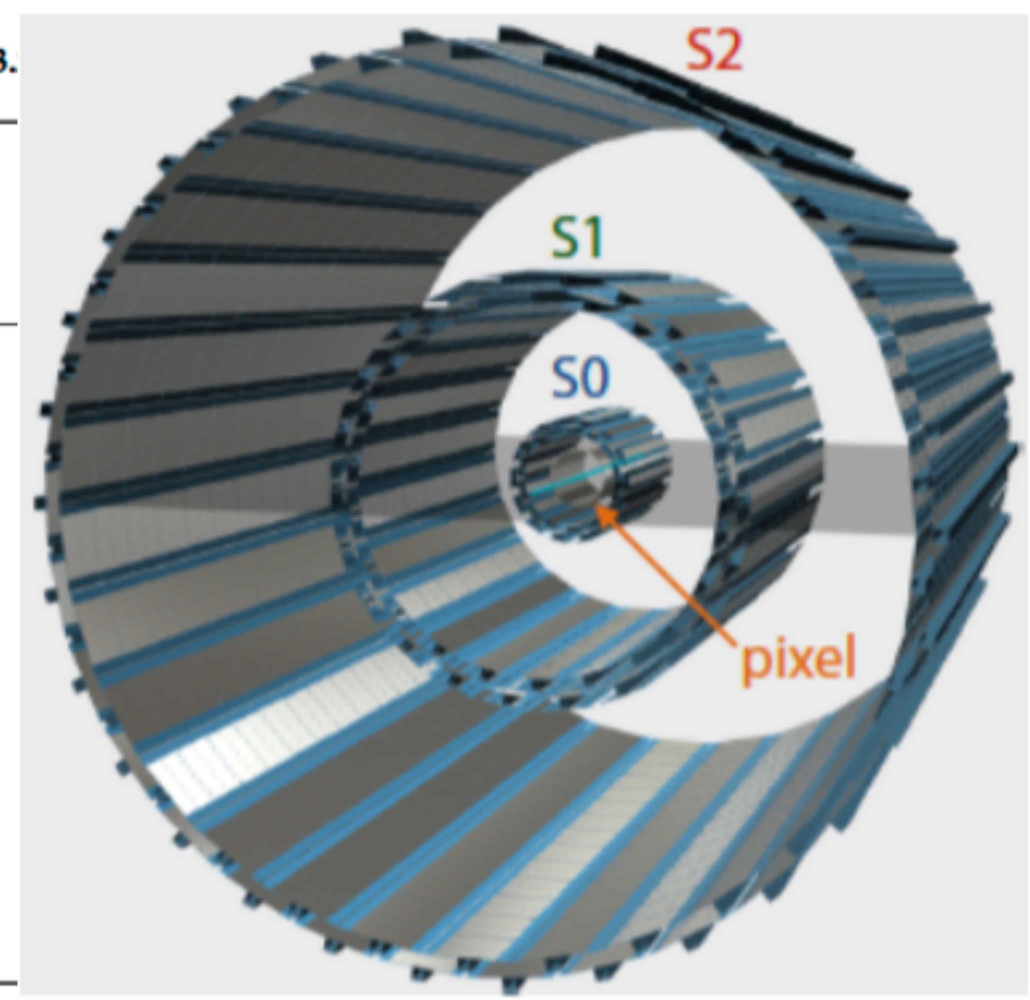
Table 3.

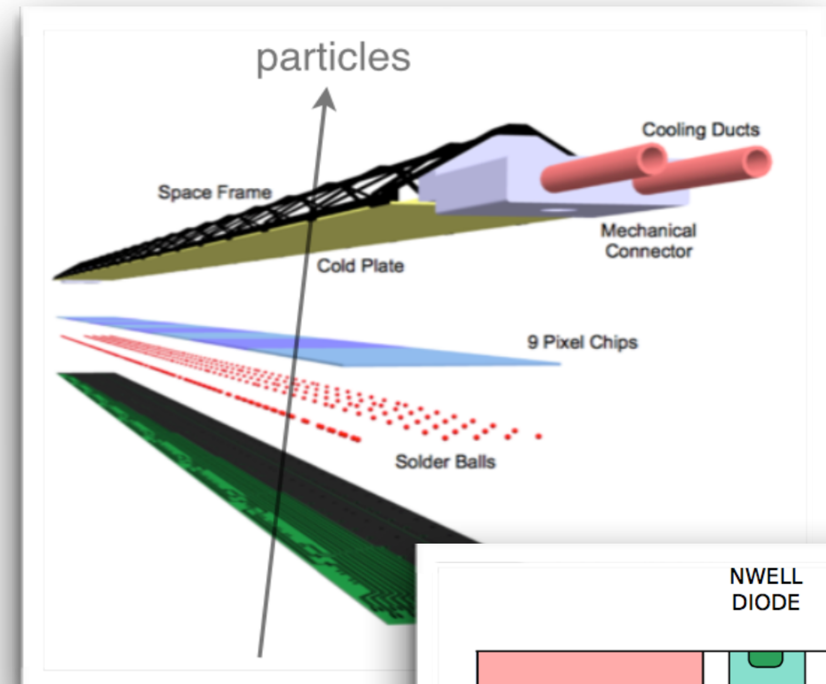
Layer	radius (cm)	area m^2
1	2.7	0.034
2	4.6	0.059
3	9.5	0.152
4	10.5	0.185
5	44.5	3.3
6	45.5	3.5
7	80.0	10.8

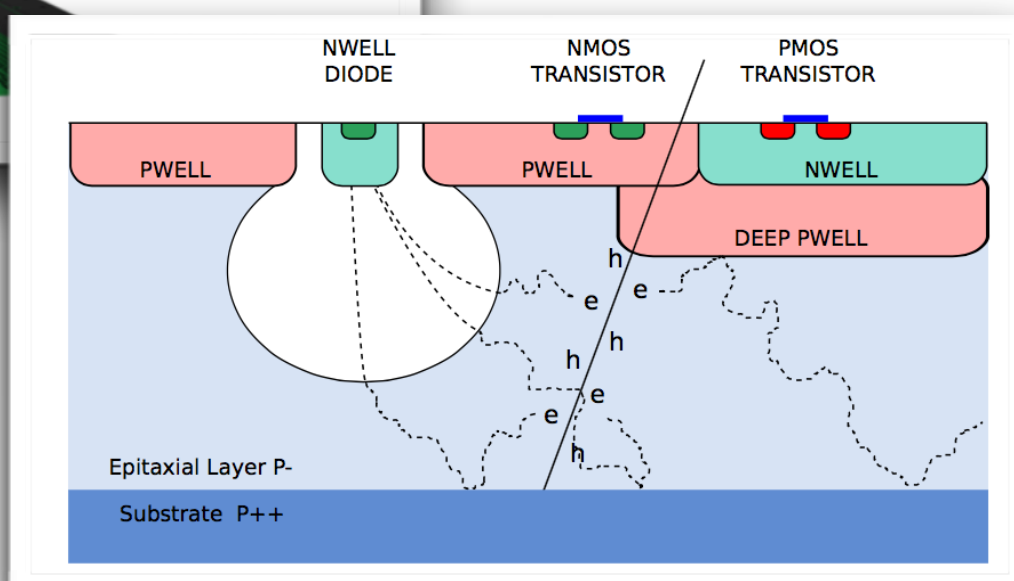


Additional Tracking Options

alternative: New Inner Pixels

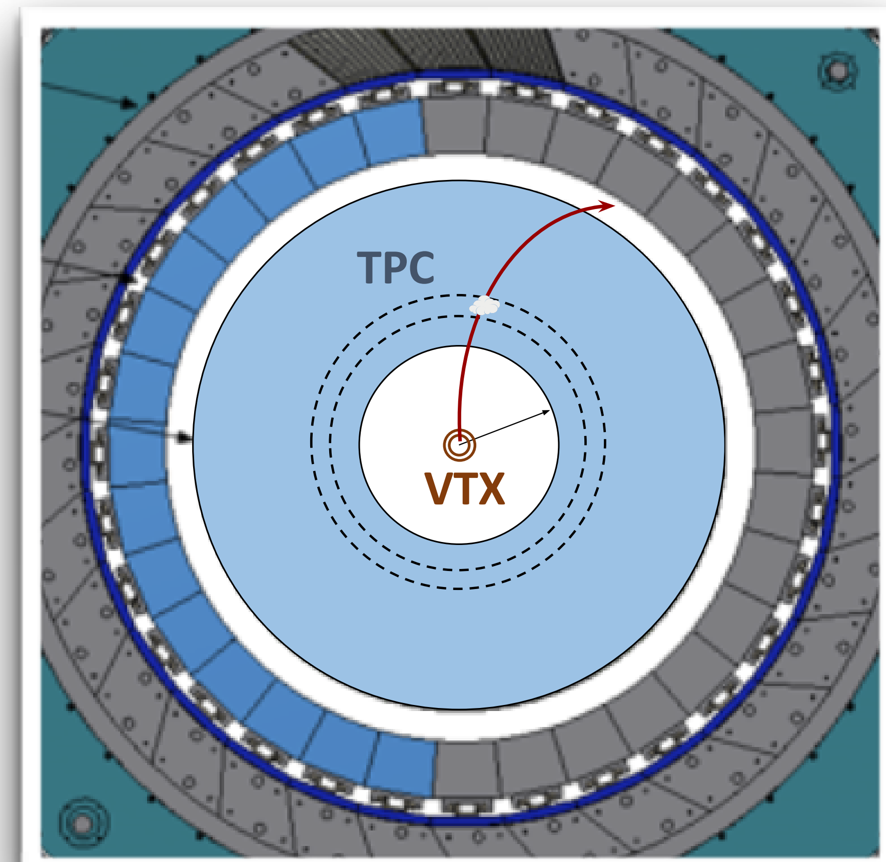
ALICE-based sensor technology





alternative: Outer TPC

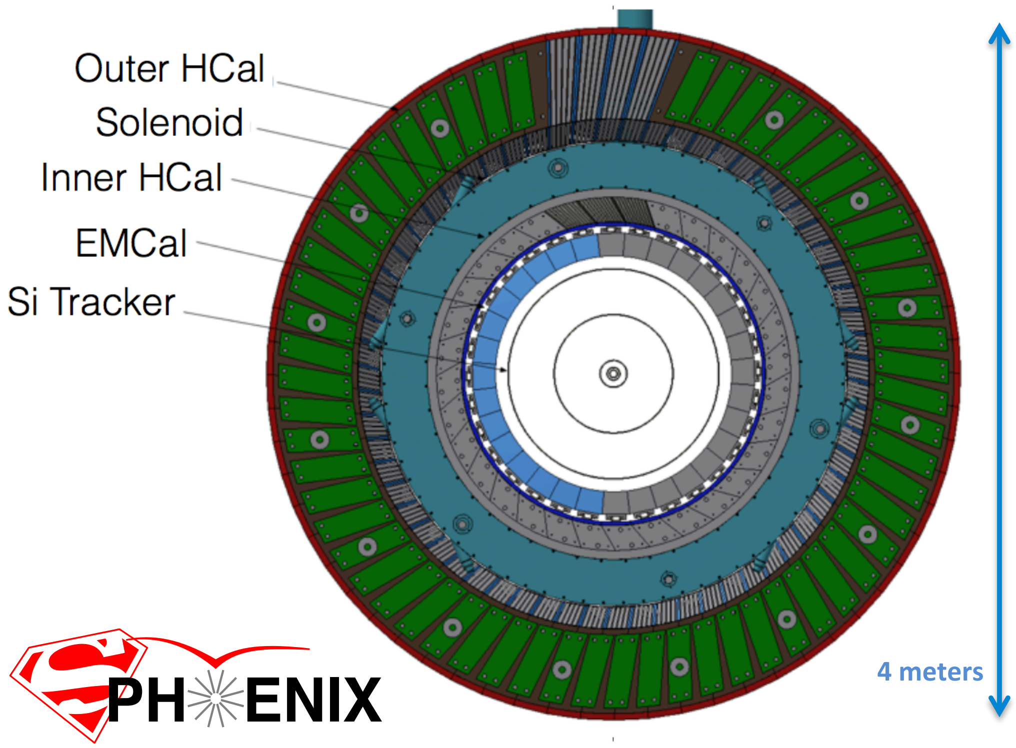
Electron-Ion Collider based technology



These options are currently under study for technical design down-select

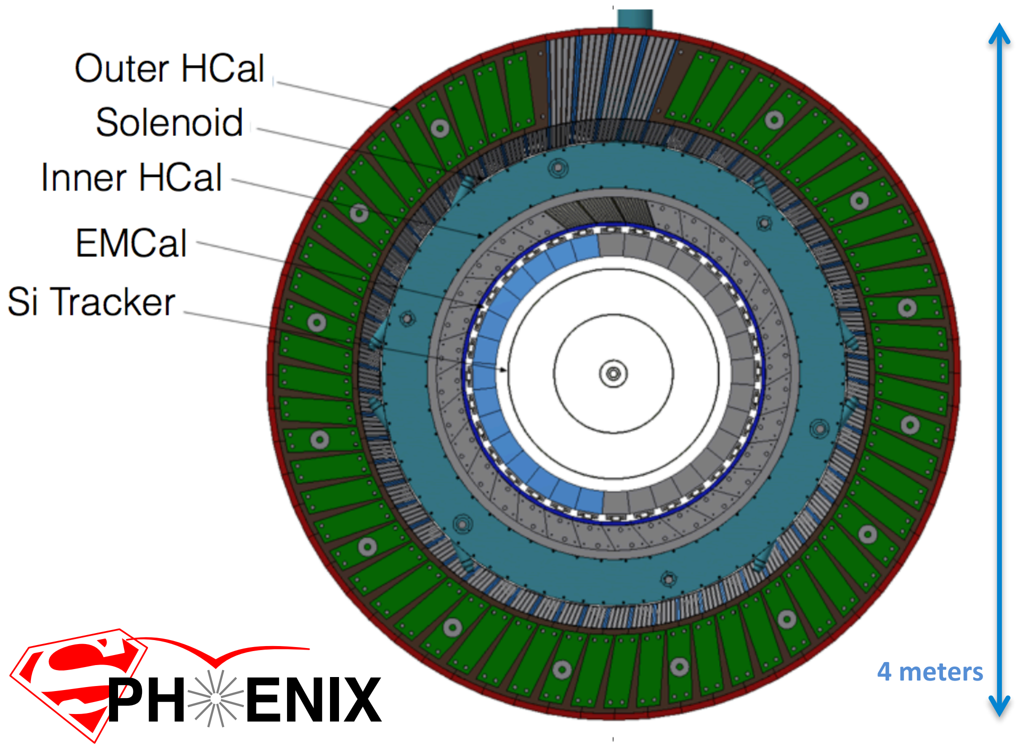
Bright Future at the PHENIX Hall

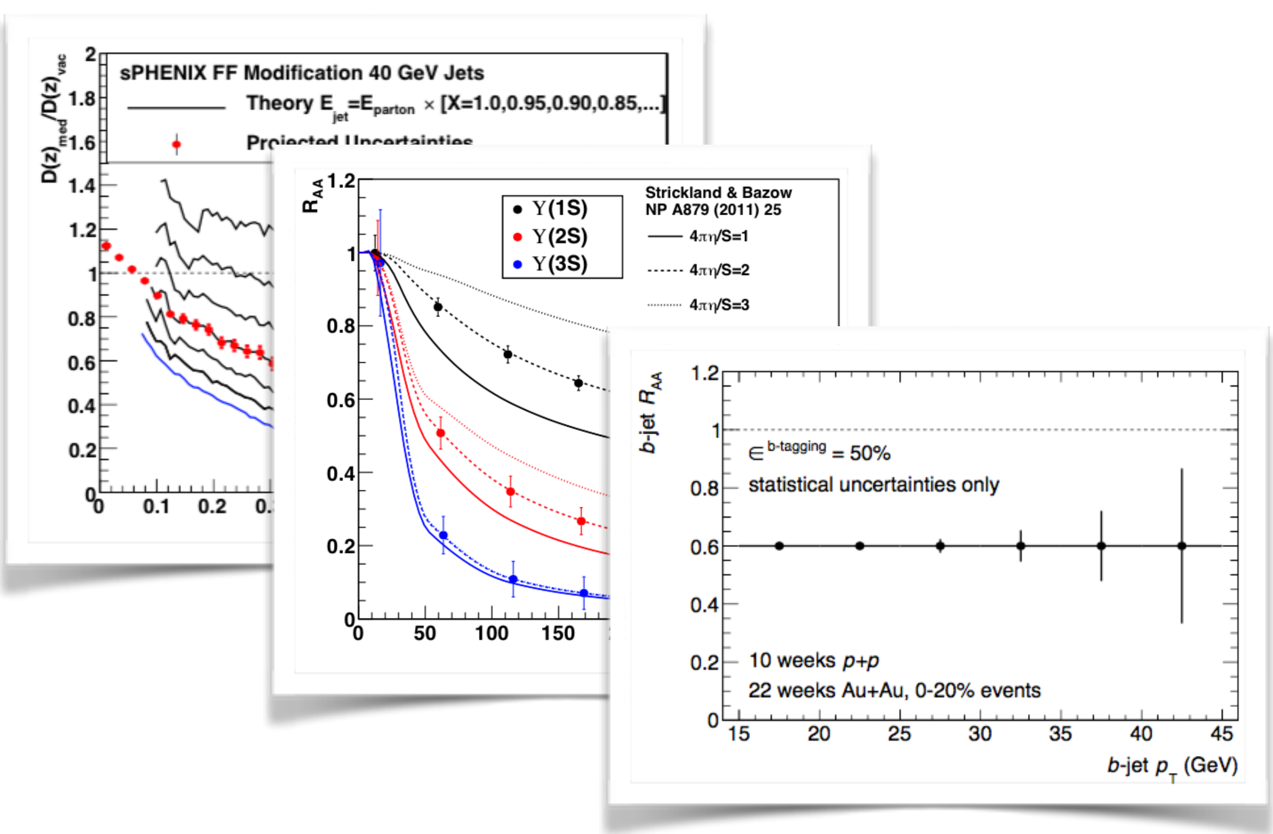
Coming in 2021…



Bright Future at the PHENIX Hall

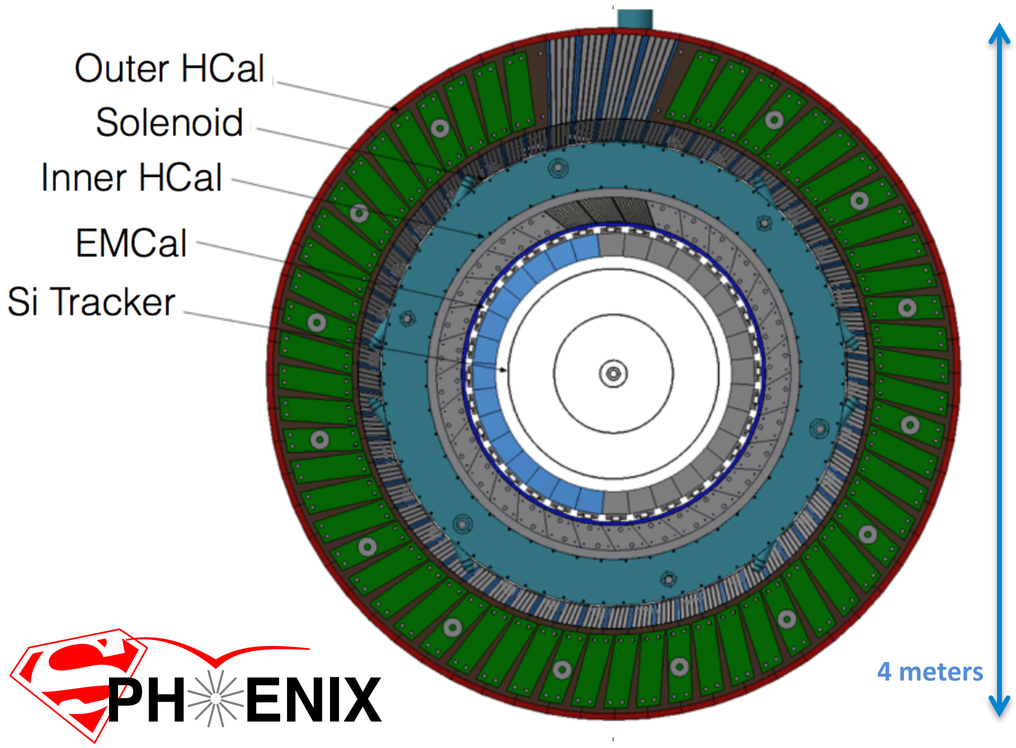
Coming in 2021…

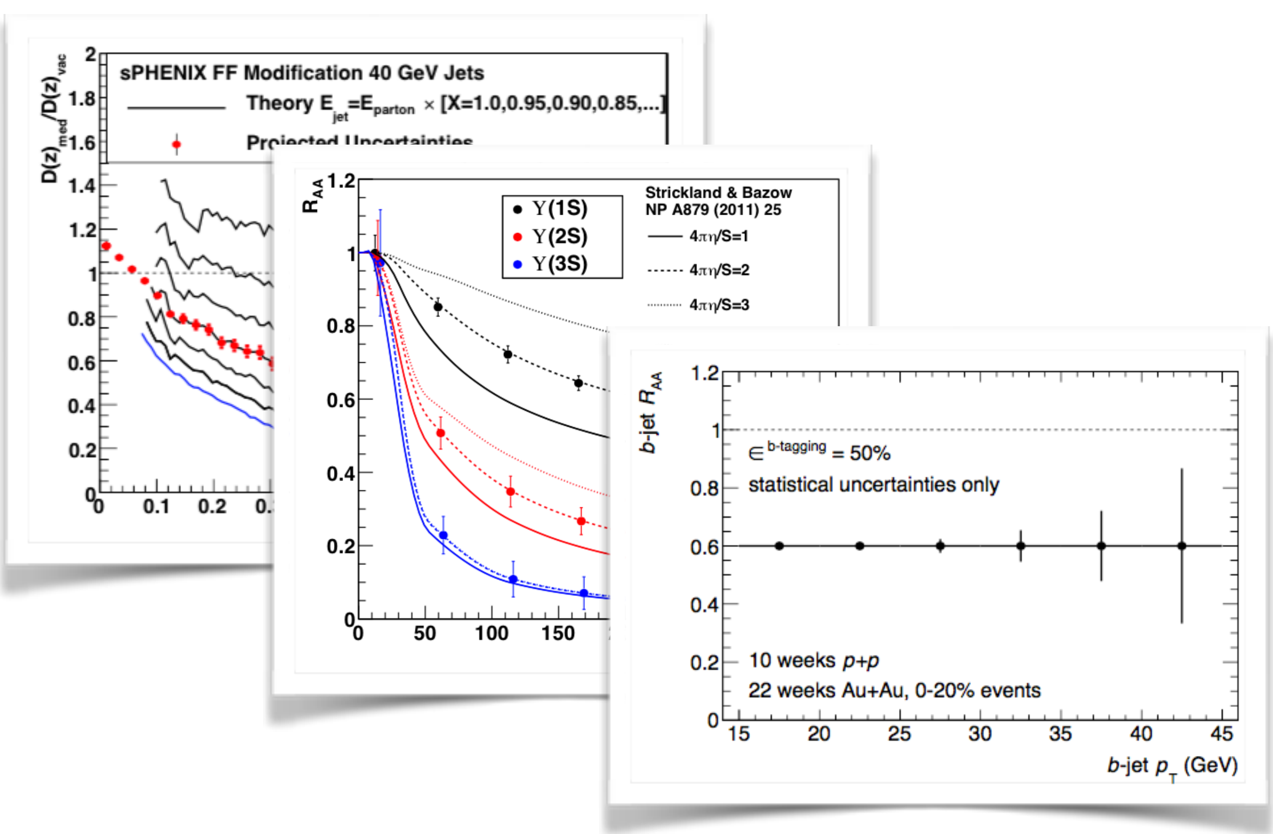




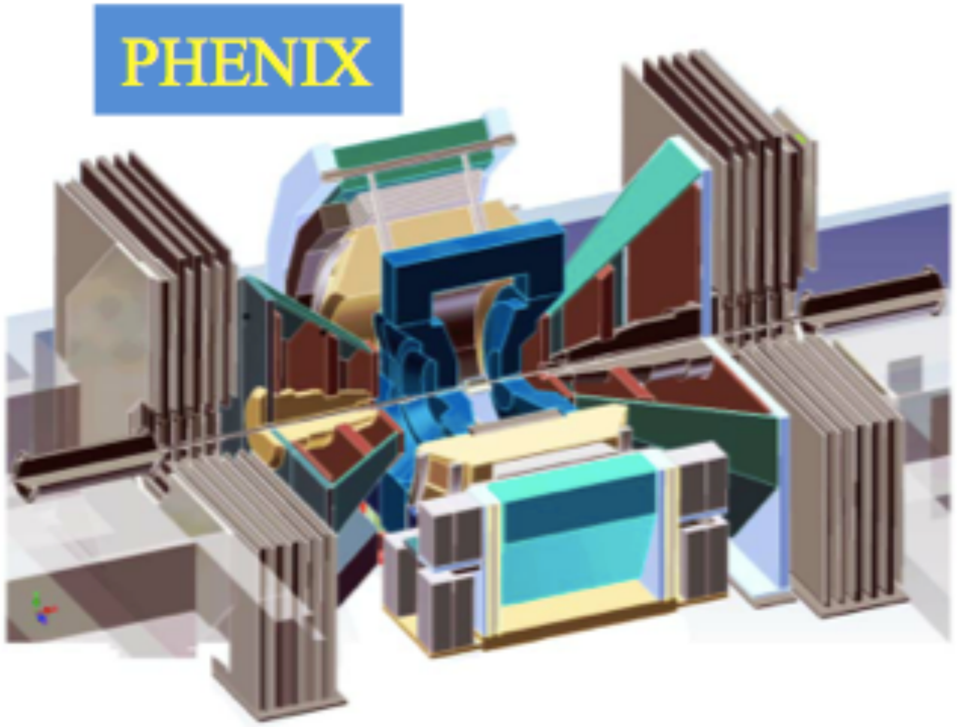
Bright Future at the PHENIX Hall

Coming in 2021…



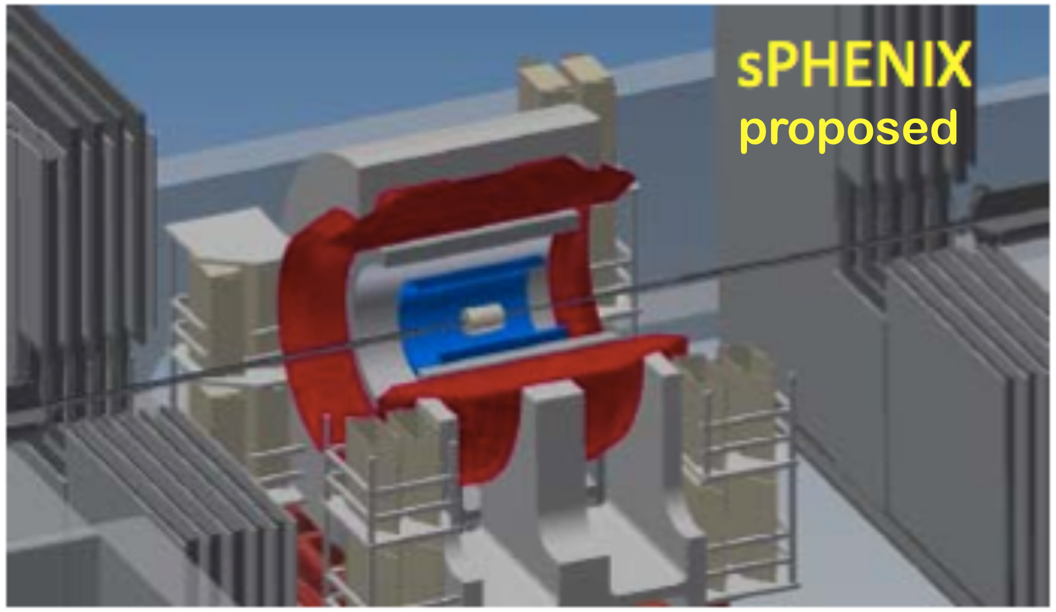


Future Vision for the PHENIX Hall

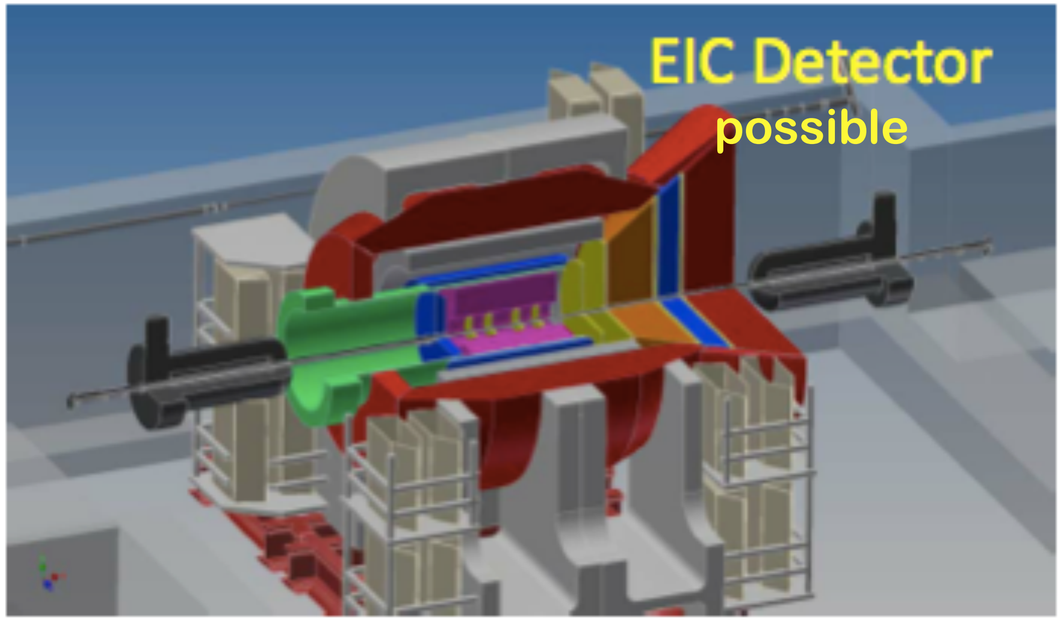


2021

Hard Probes of QGP

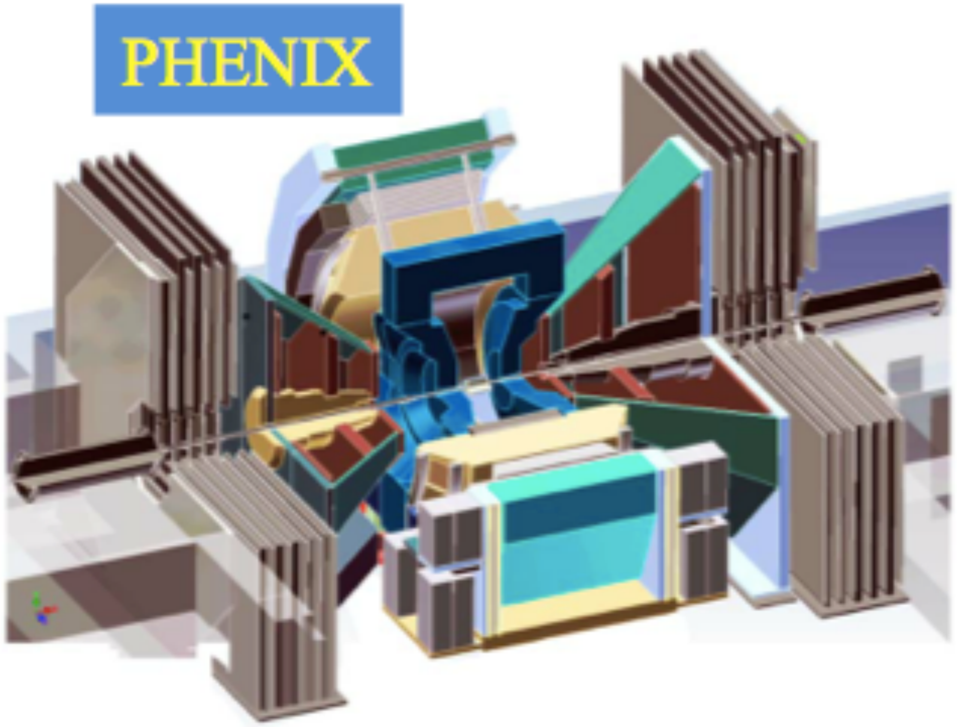


~2025



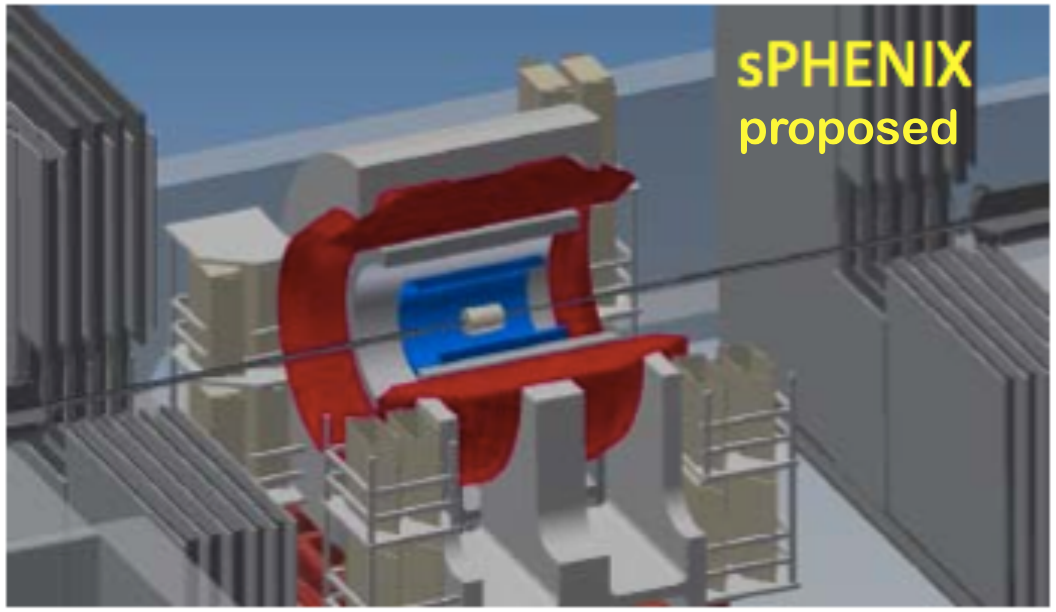
Nuclear Structure via e+{p,A}

Future Vision for the PHENIX Hall



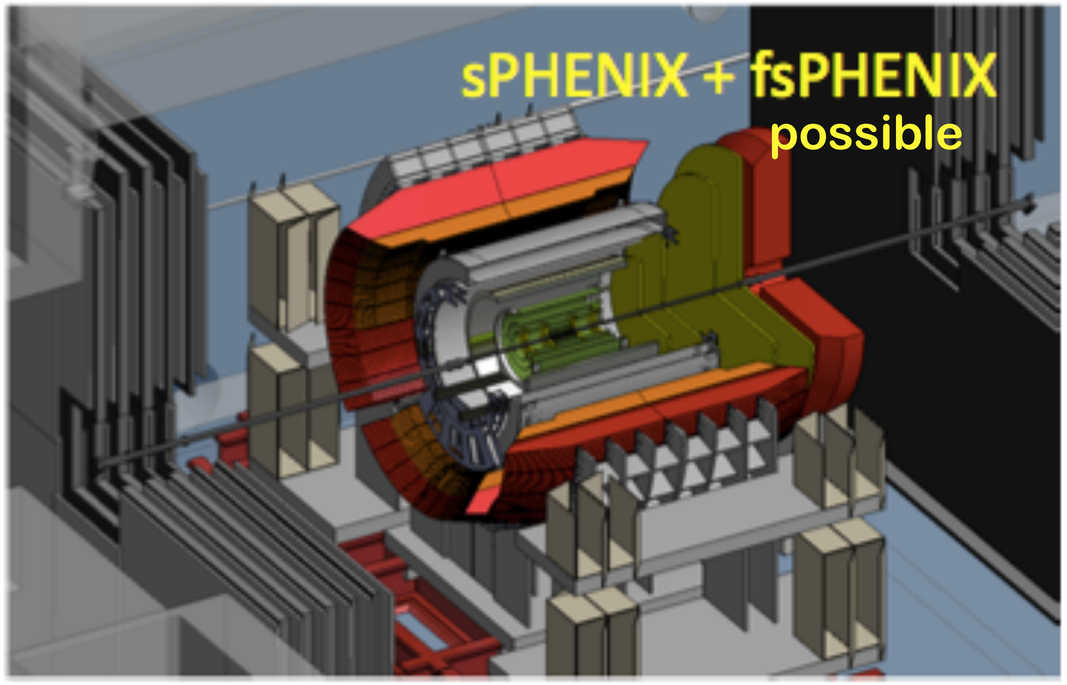
2021

Hard Probes of QGP



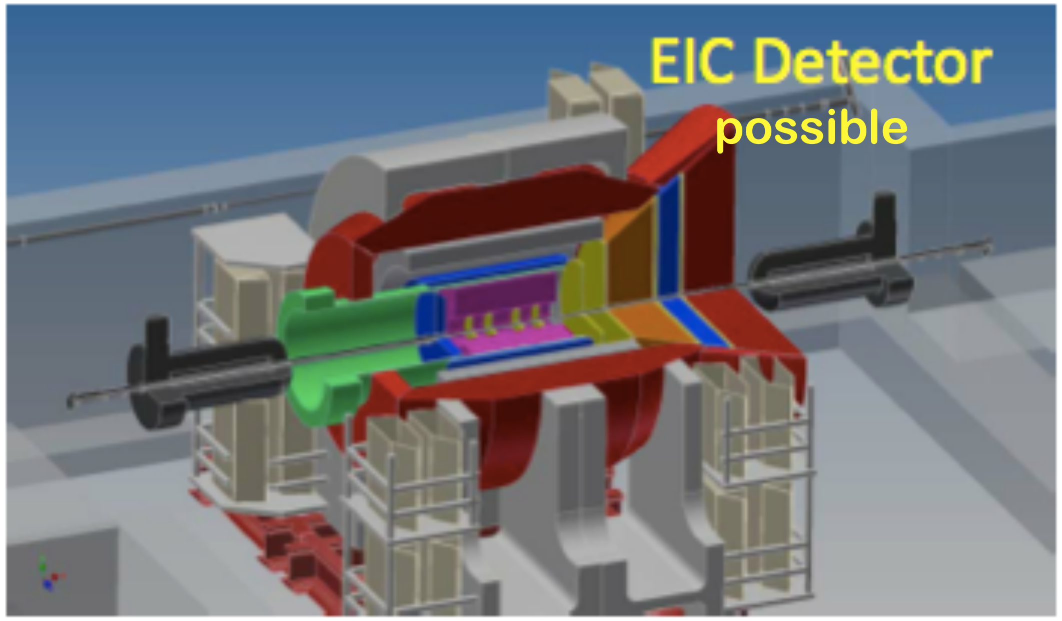
~2025

Hard Probes of QGP



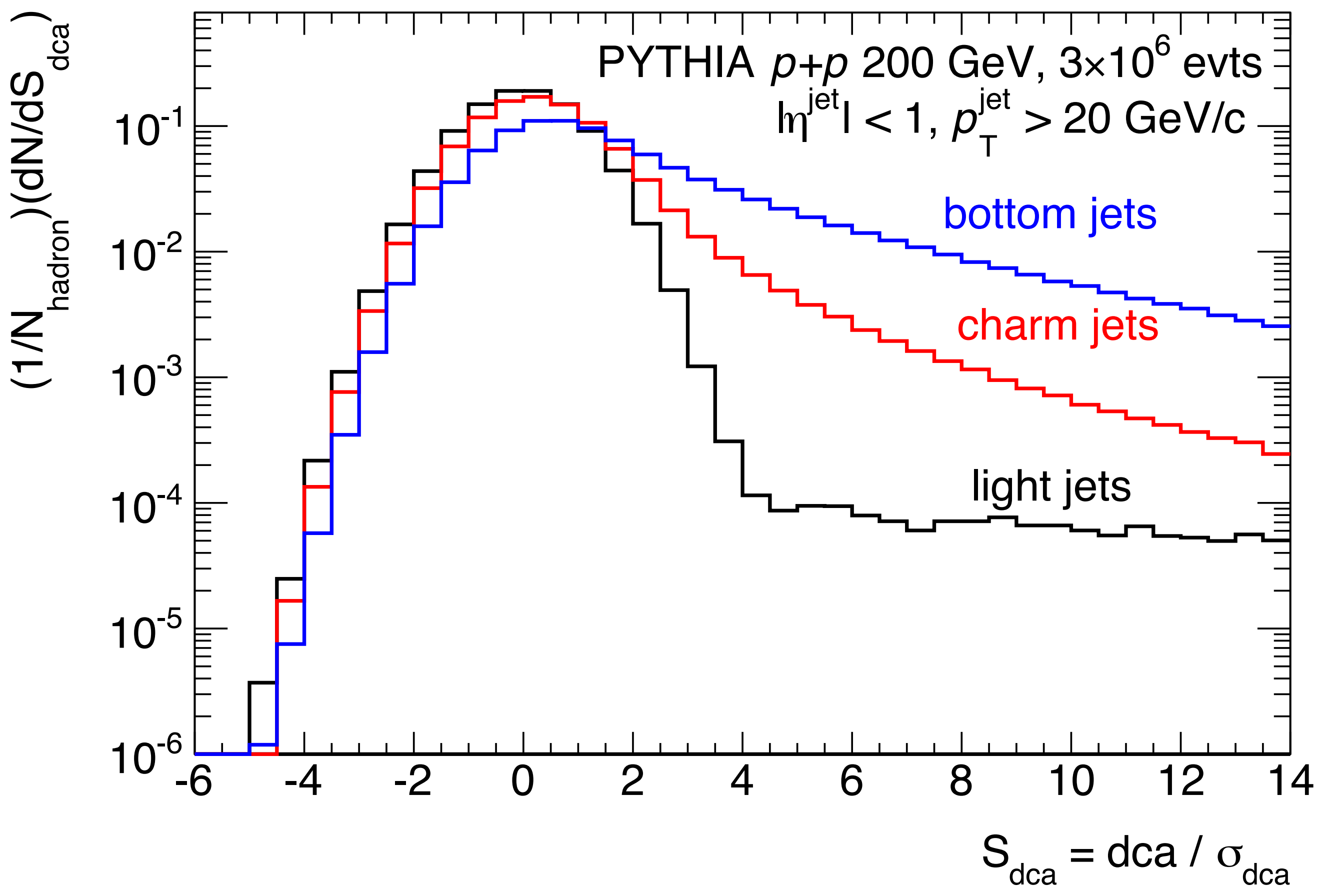
+ Nuclear Structure via p+{p,A}

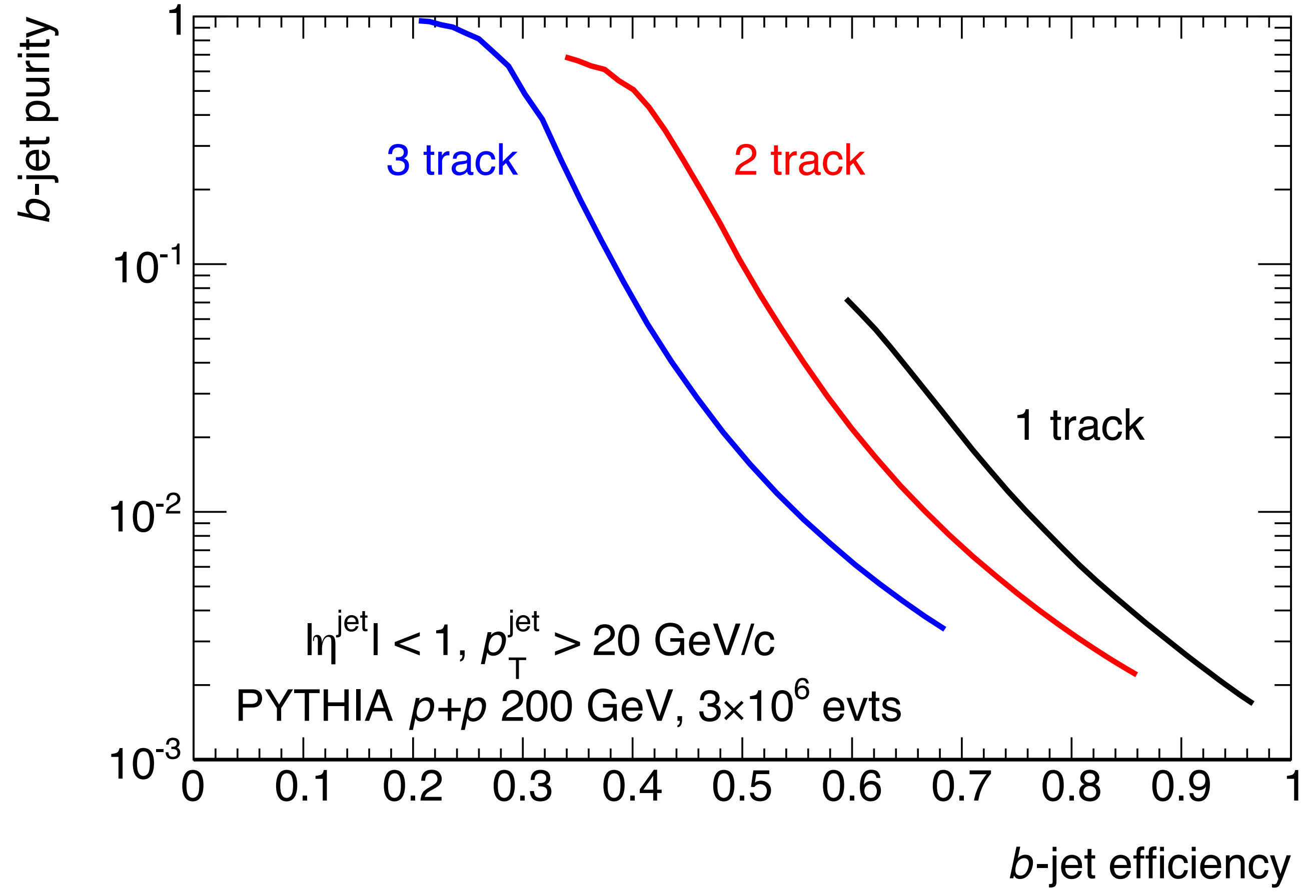
>2025



Nuclear Structure via e+{p,A}

B-Jet Identification





sPHENIX has explored b-jet tagging through requiring tracks in the jet with **a large 2-D distance of closest approach** (d.c.a) to the primary vertex

Fast simulation using parameterized detector responses (inc. vertex resolution of 70 μm)

Reasonable efficiency vs purities can be achieved.

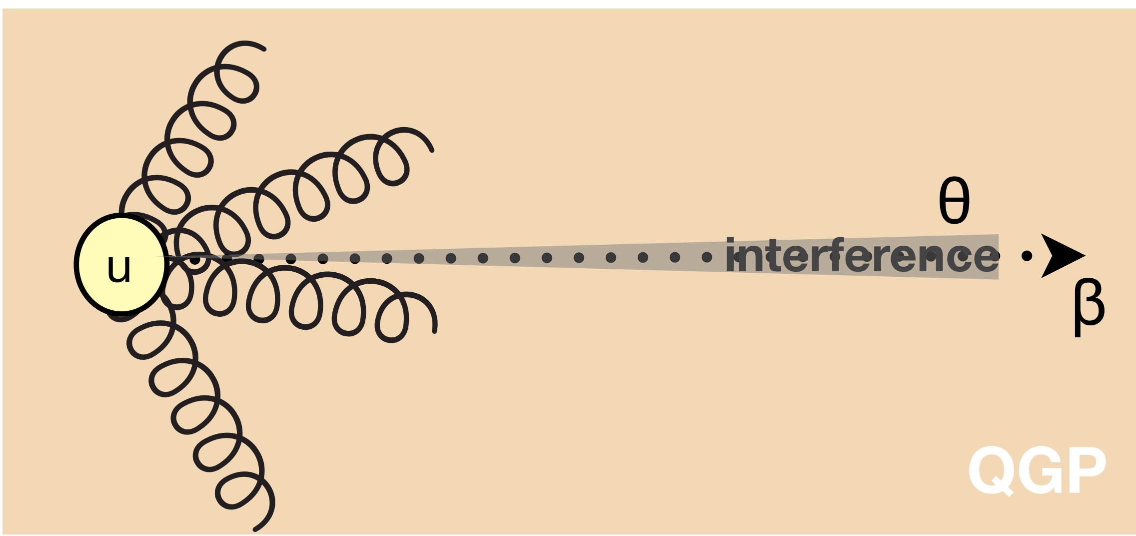
Preserve as design criteria during follow-up GEANT4 studies

sPHENIX excels: b-jet Channel

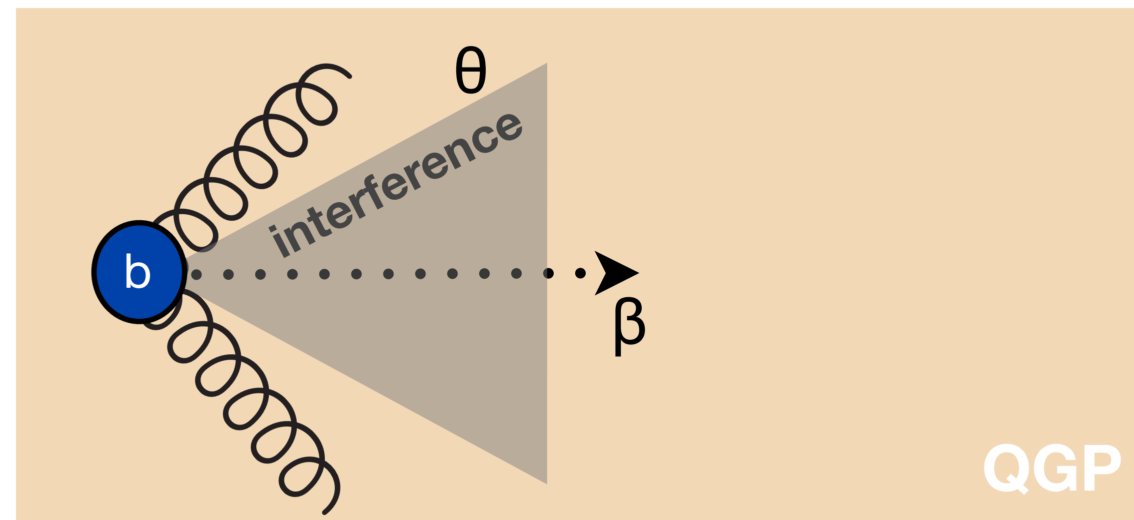
Why **Bottom** Quarks? They're heavy!

- competition between **gluon radiation and collisional energy loss**
- **"Dead cone effect"** on gluon radiation (proposed Dokshitzer & Kharzeev, 2001)
- More sensitive to **collisions with constituents within the plasma**

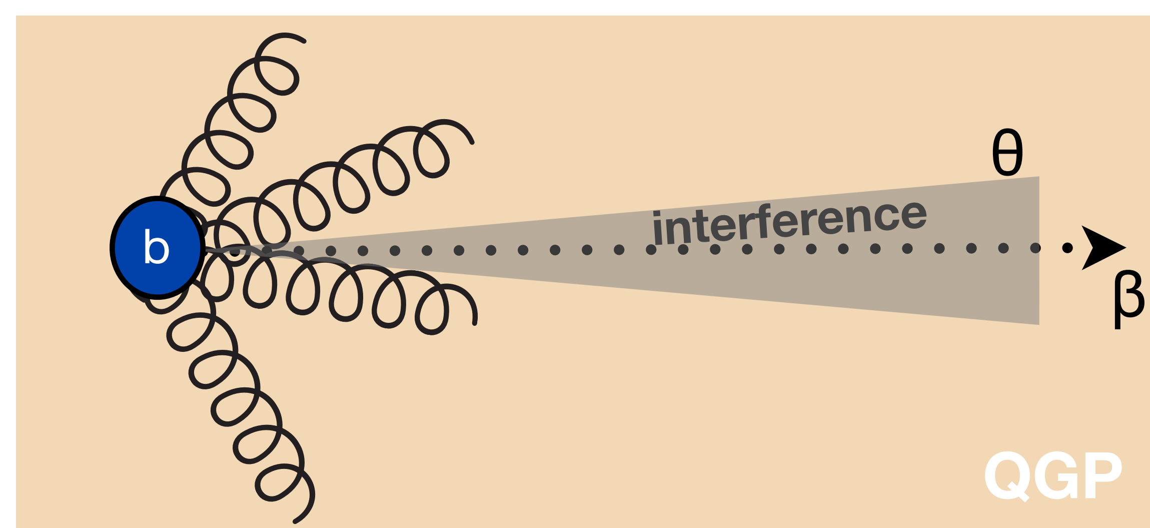
light up quark



slower bottom quarks



faster bottom quarks

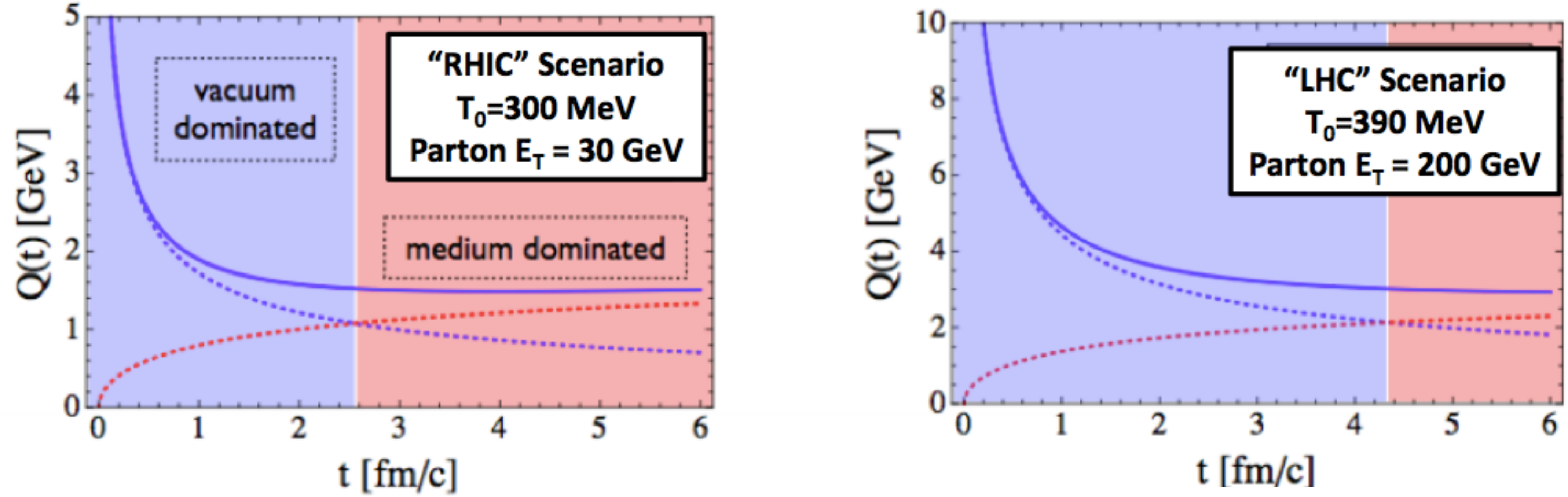


mass-ordering of energy loss:

$$\Delta E_g > \Delta E_{u,d} > \Delta E_c > \Delta E_b$$

sPHENIX: unique jets

B. Muller. Nucl.Phys., A855:74–82, 2011

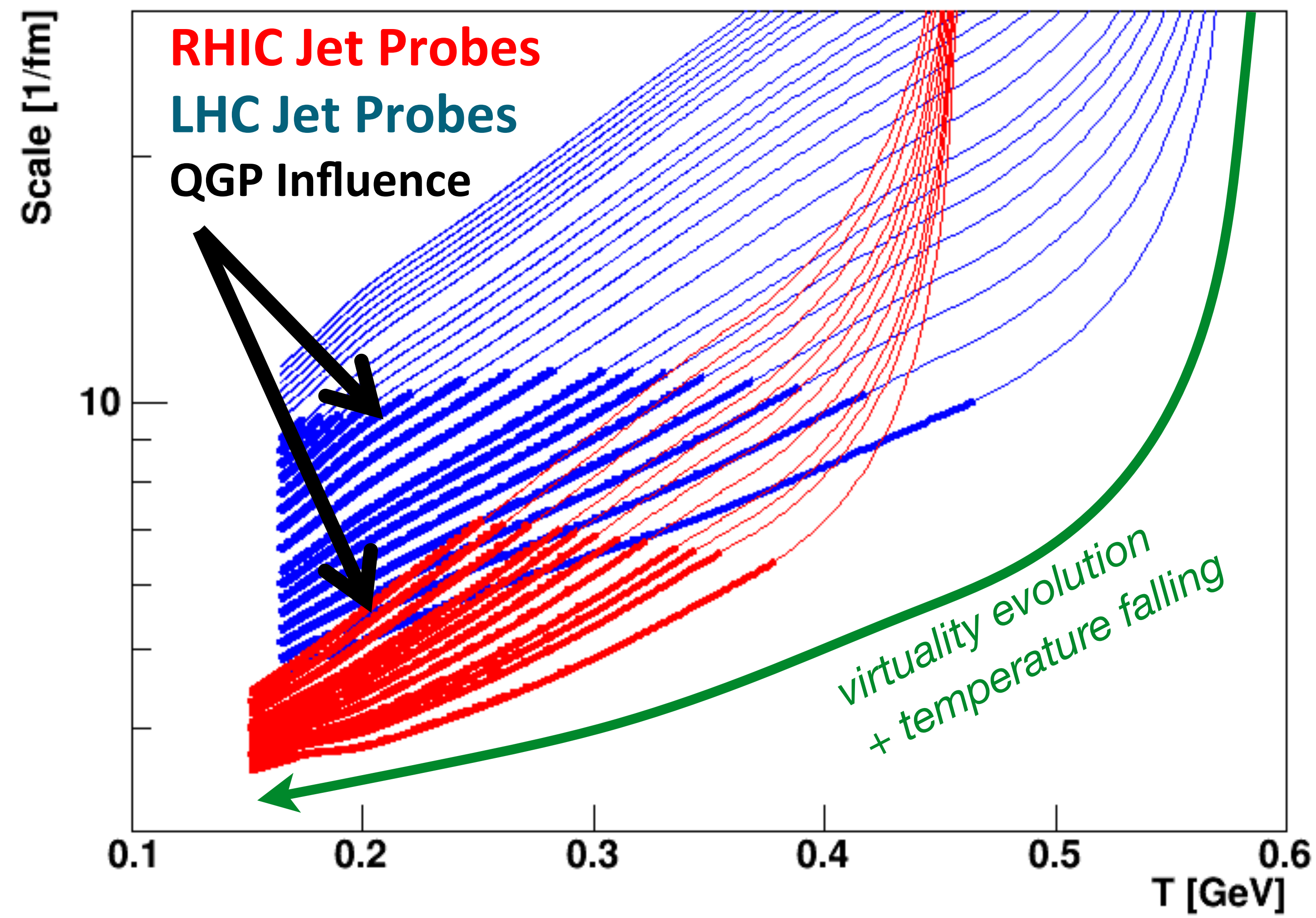


Quark Gluon Plasma at RHIC interactions **dominates** jet evolution:

for a **larger time fraction**

at **larger length scales** in medium

at **temperatures closer to T_c**



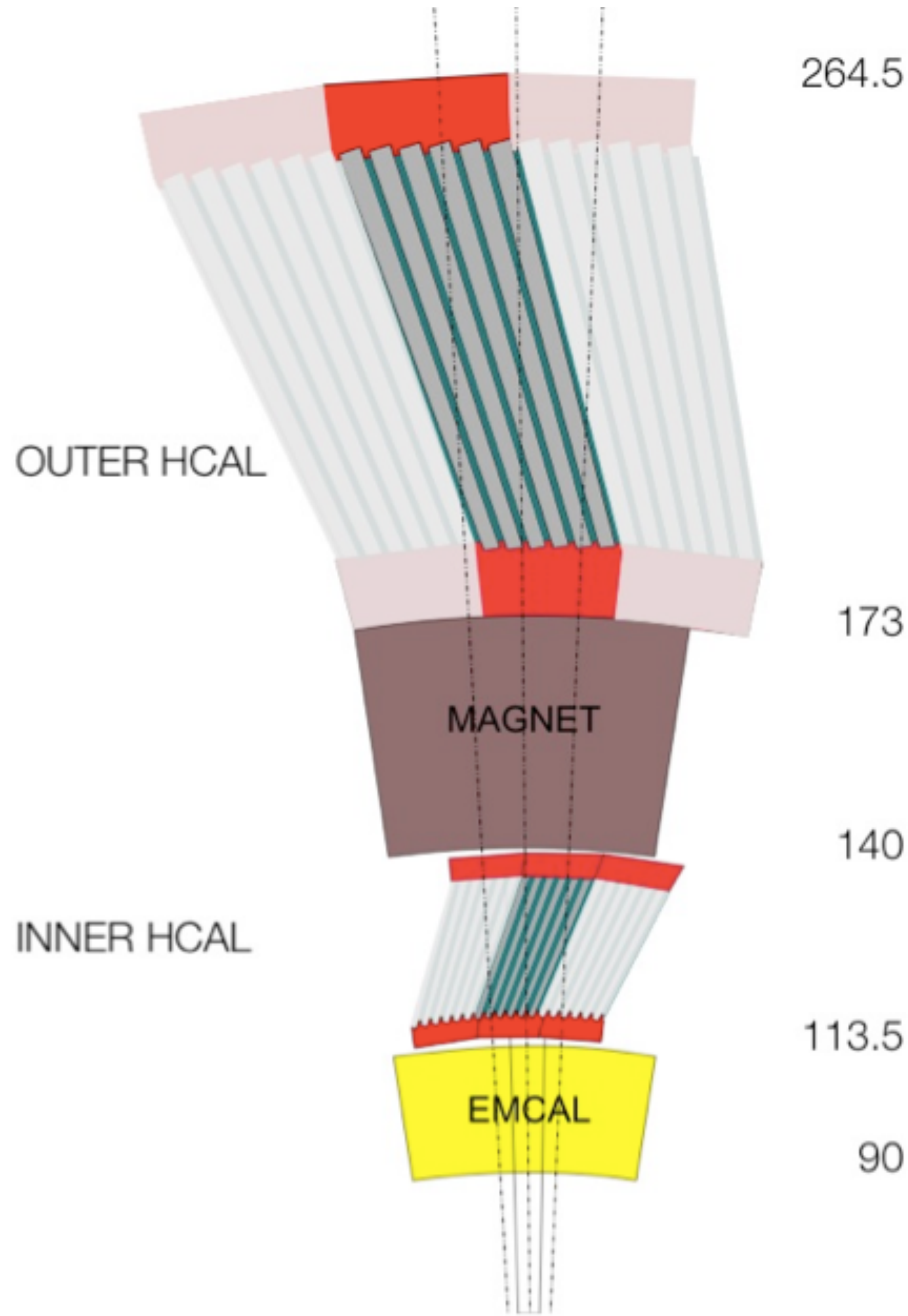
sPHENIX Calorimeters

Total = 6λ

- EMCAL ≈$18X_0$≈$1\lambda_I$
- Inner HCAL ≈$1\lambda_I$
- Magnet ≈$1X_0$
- Outer HCAL ≈$4\lambda_I$

HCal 5λ deep (plus EMCal 1λ deep) leads to few percent energy leakage for hadrons above 50 GeV; comparable to other contributions to energy resolution constant term.

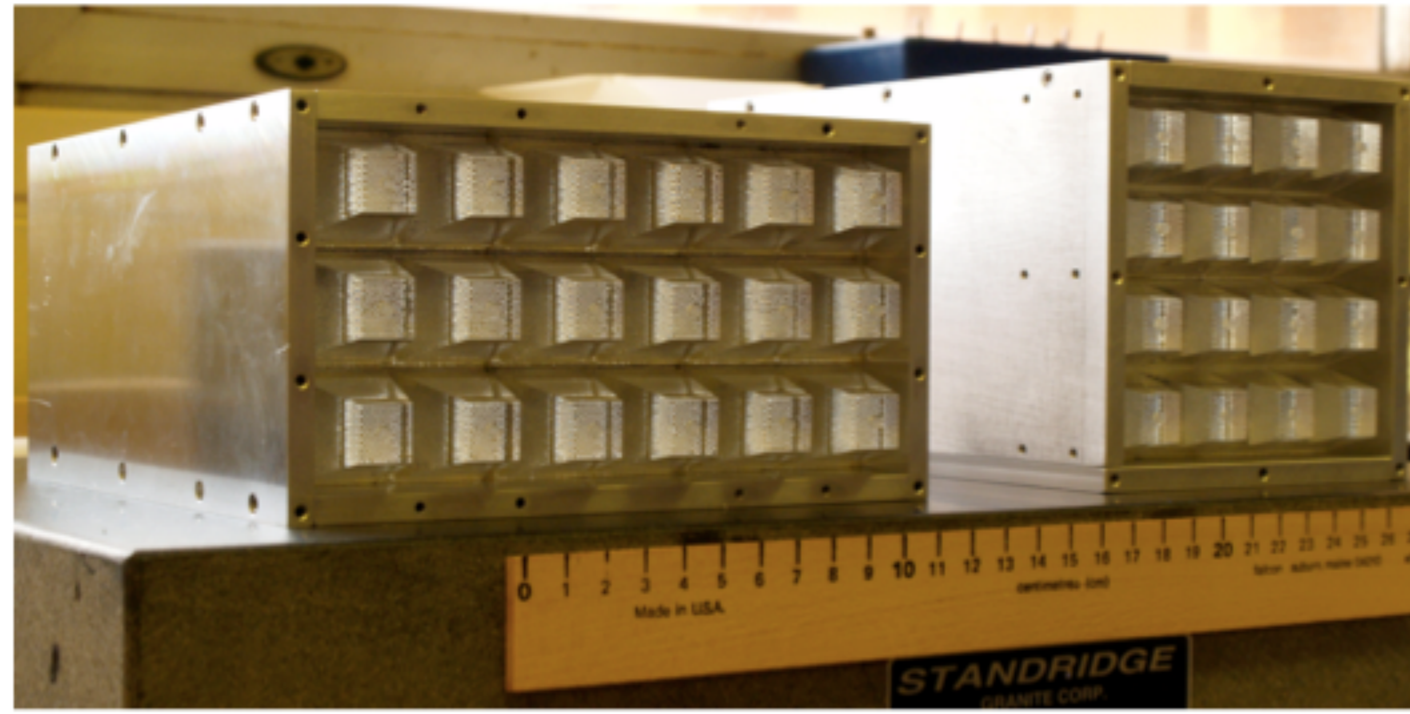
Key difference with calorimeters for much higher energy jets.



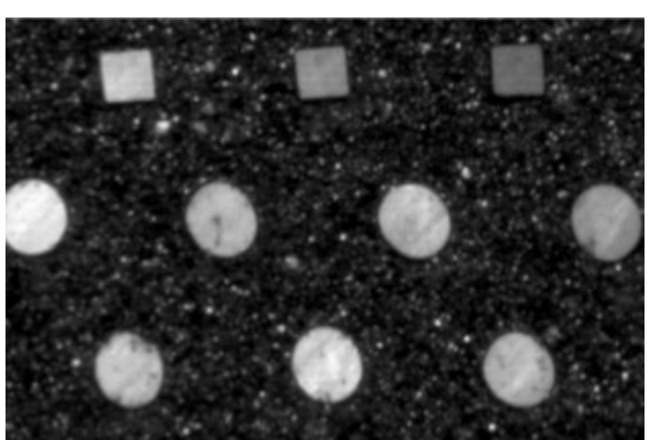
p+p jet energy resolution ~ 65% / sqrt(E)

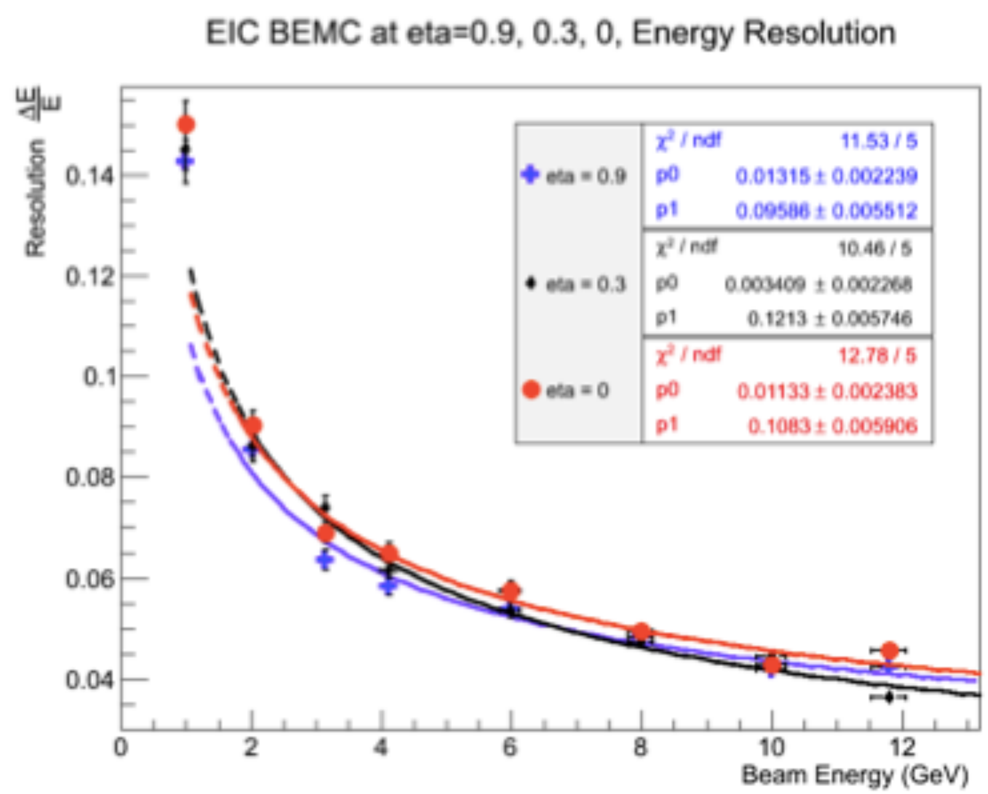
EMCAL SPACAL Option

- 18 X_0 deep
- 2.3 cm $R_M \approx$ cell size
- 256x96 = 24,576 channels
- Sampling fraction ≈ 2%
- Resolution ≈ 12%/√E
- ≈ 500 pe/GeV



SPACAL prototypes (Tsai)

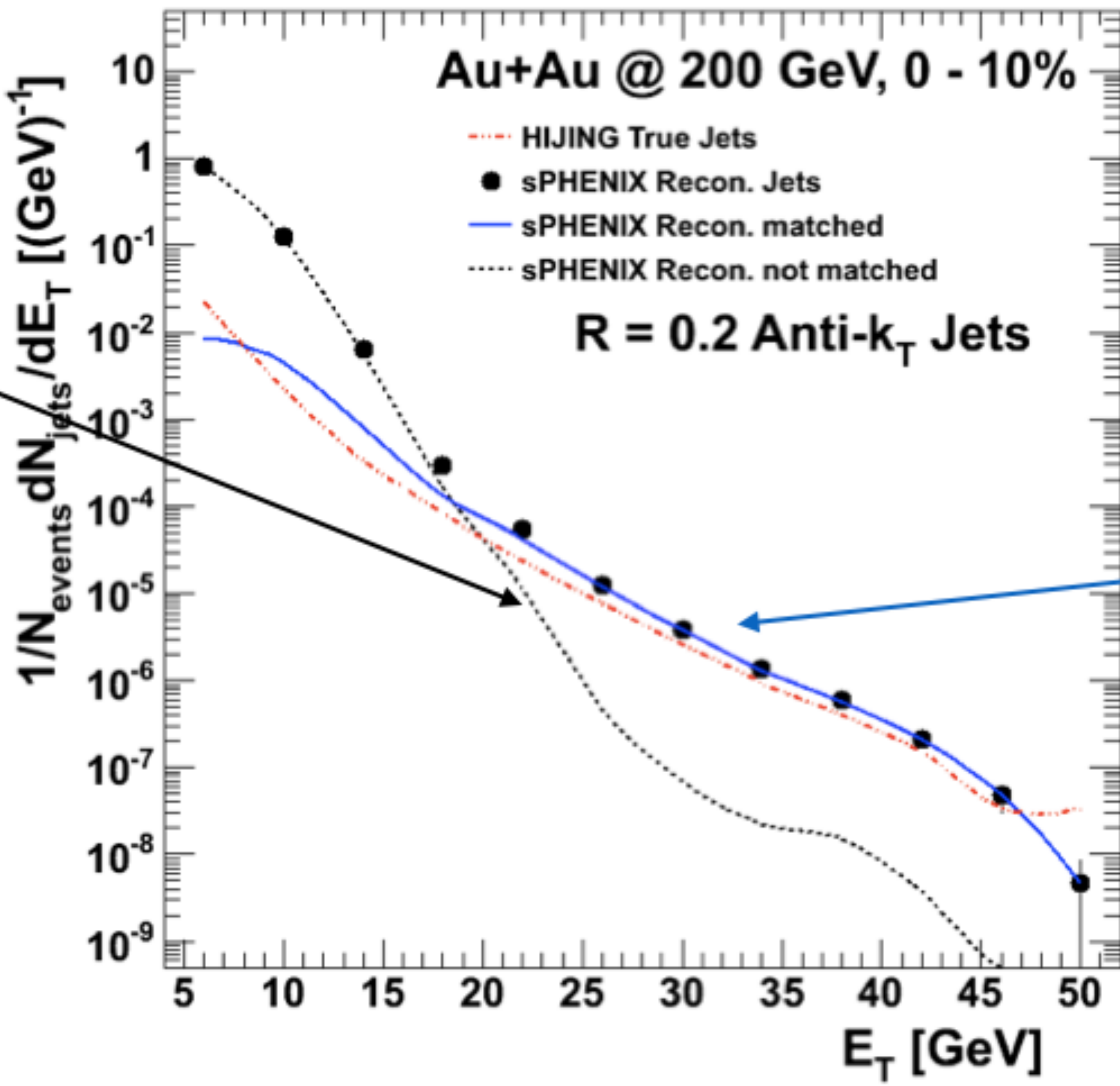




FNAL T-1018 results

Smaller Backgrounds from Fake Jets

fake jets



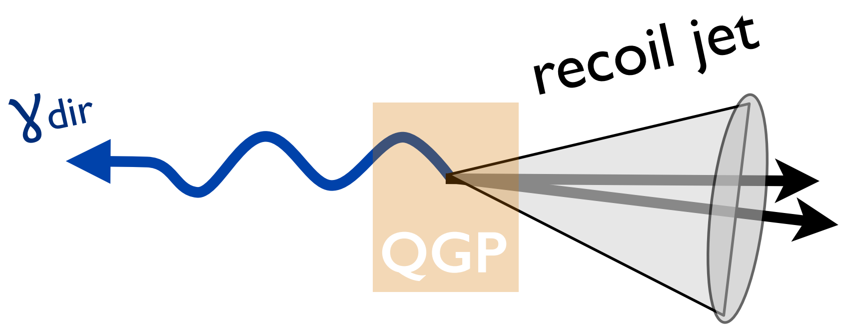
true jets

for R=0.2 jets, > 20 GeV real jets dominate in HIJING

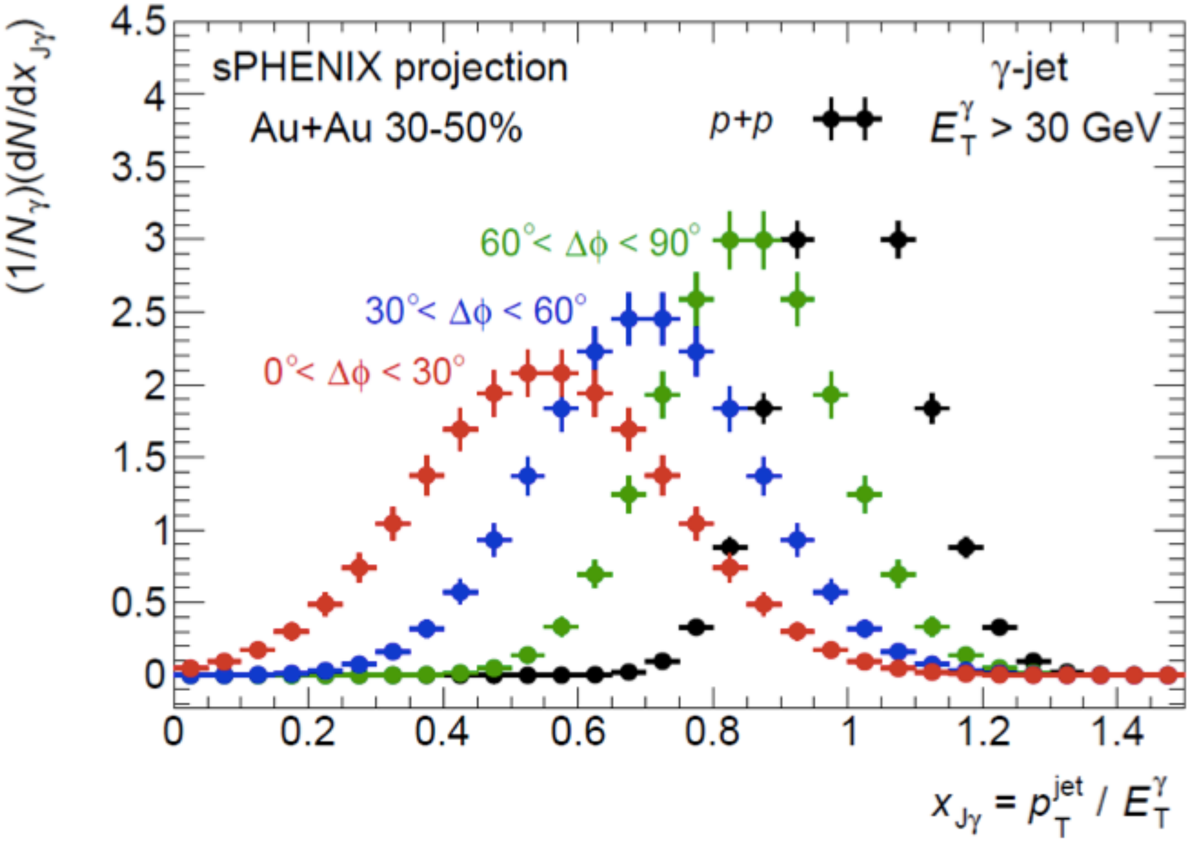
for R=0.4 jets, > 35 GeV

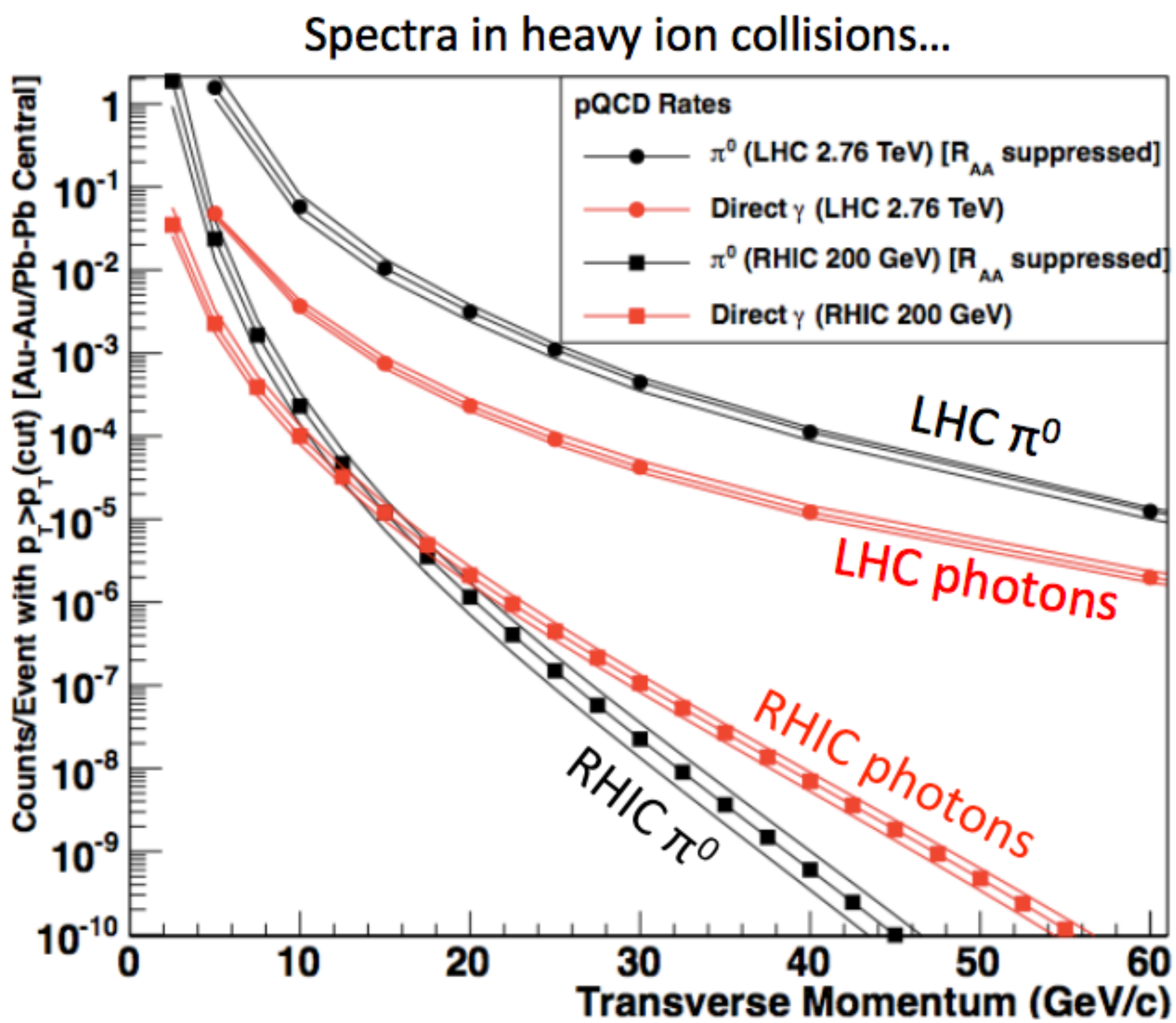
enables broad coverage without jet fragmentation bias

sPHENIX excels: Direct Photon Channel



Direct photon constrains the initial jet energy…



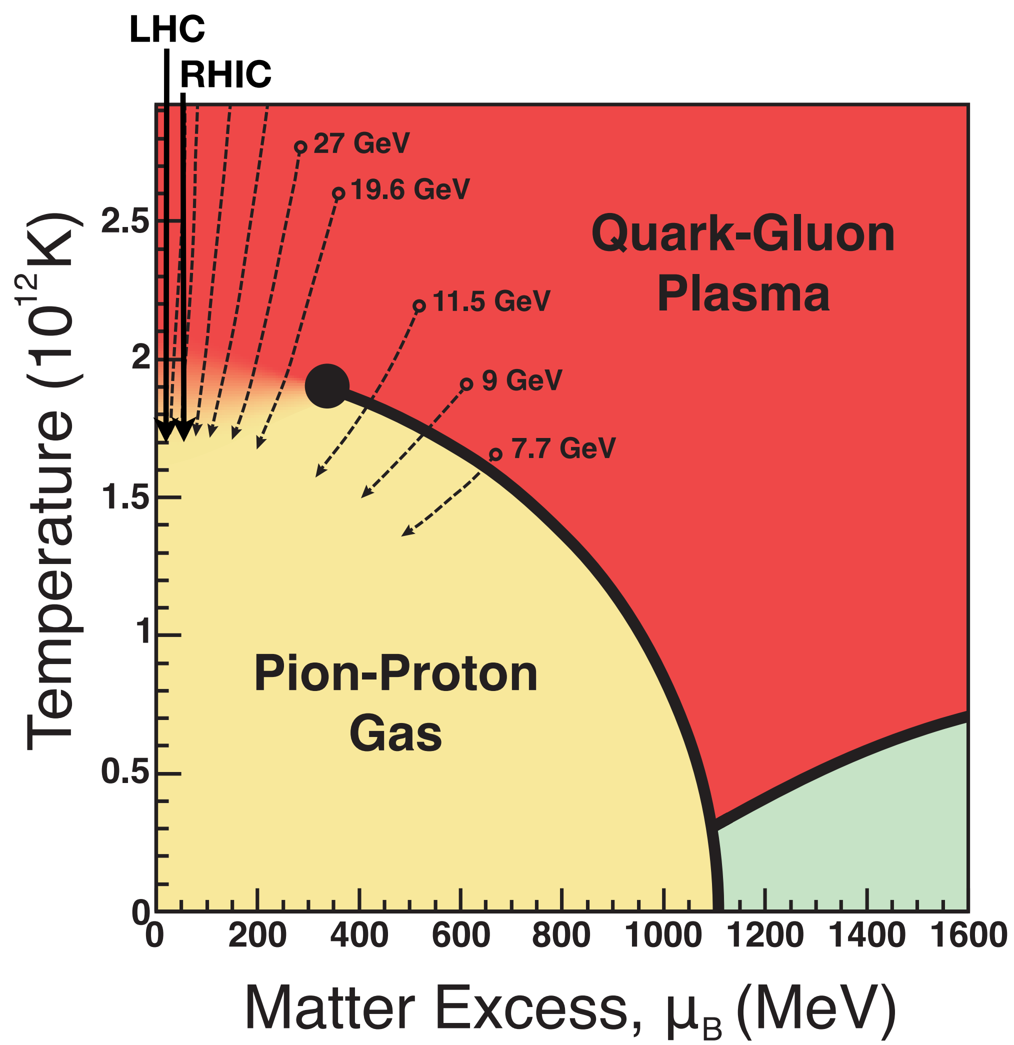


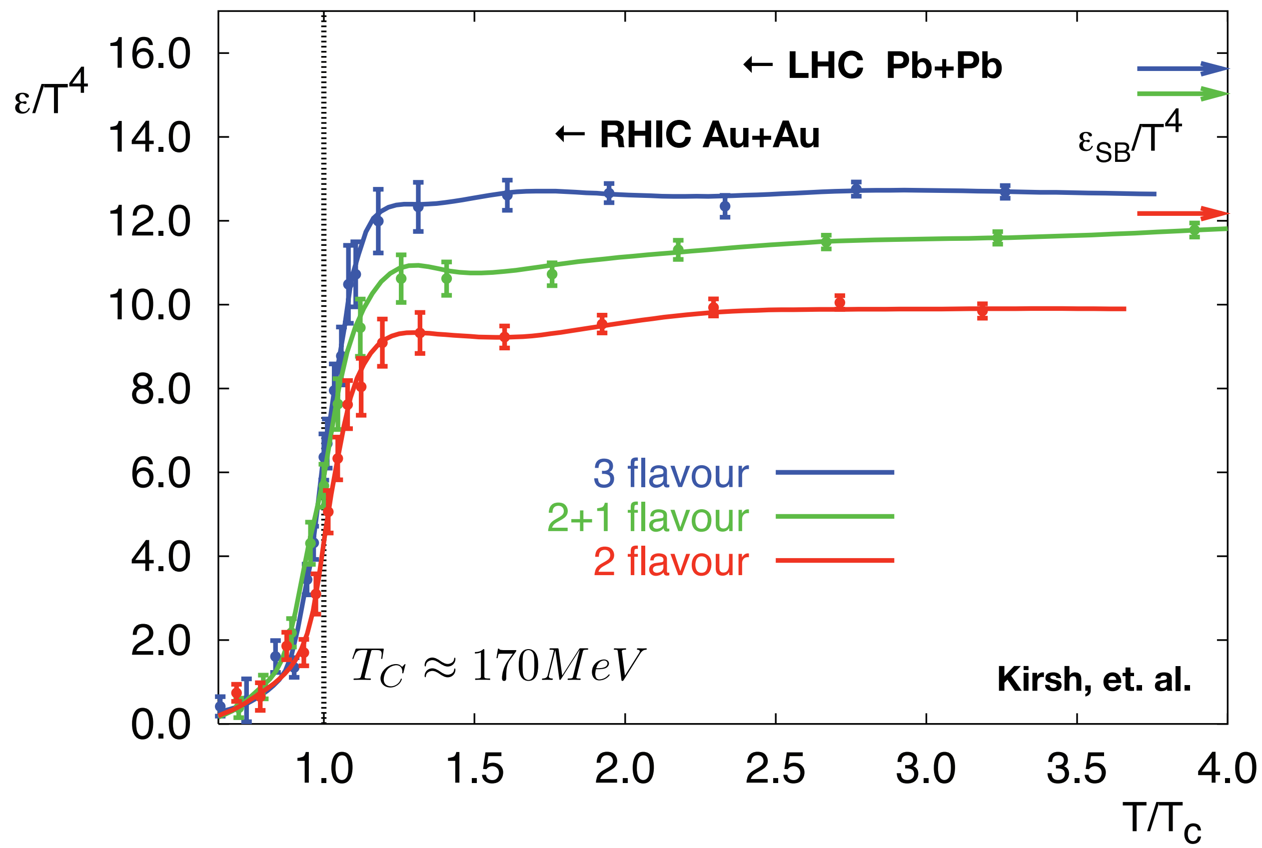
Large S/B unique to RHIC yields high precision results in the energy loss “golden channel”

Heavy Ion Collisions

QCD Phase Diagram

- Quark-gluon plasma above a few 10^{12} K
- Reachable by collider facilities
- Critical point being sought

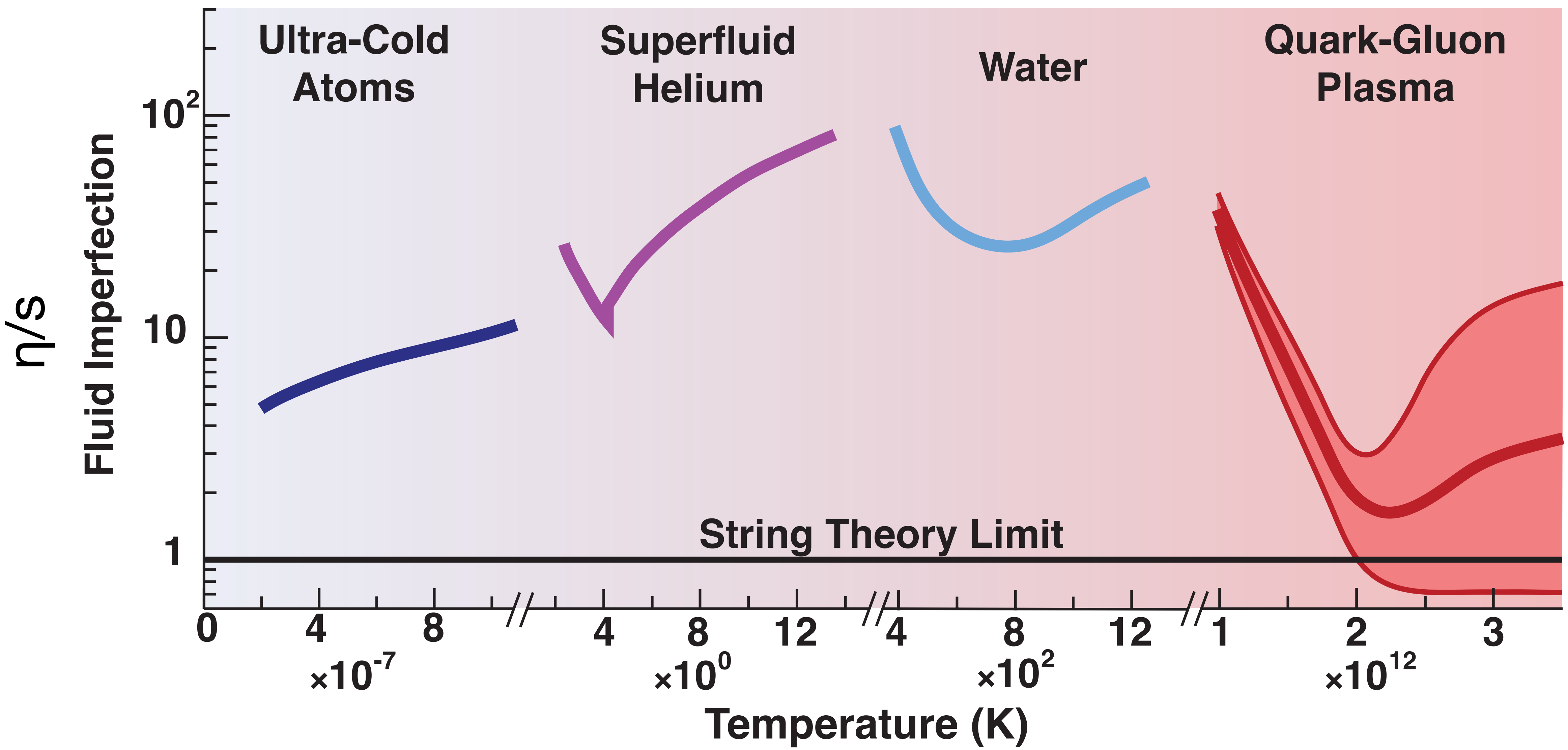




Lattice QCD Calculations

- Energy density indicates partonic degrees of freedom open at $T_c \approx 170$ MeV
- Ideal gas of quarks and gluons at arbitrarily large T
- (Data) Strongly-coupled fluid near T_c

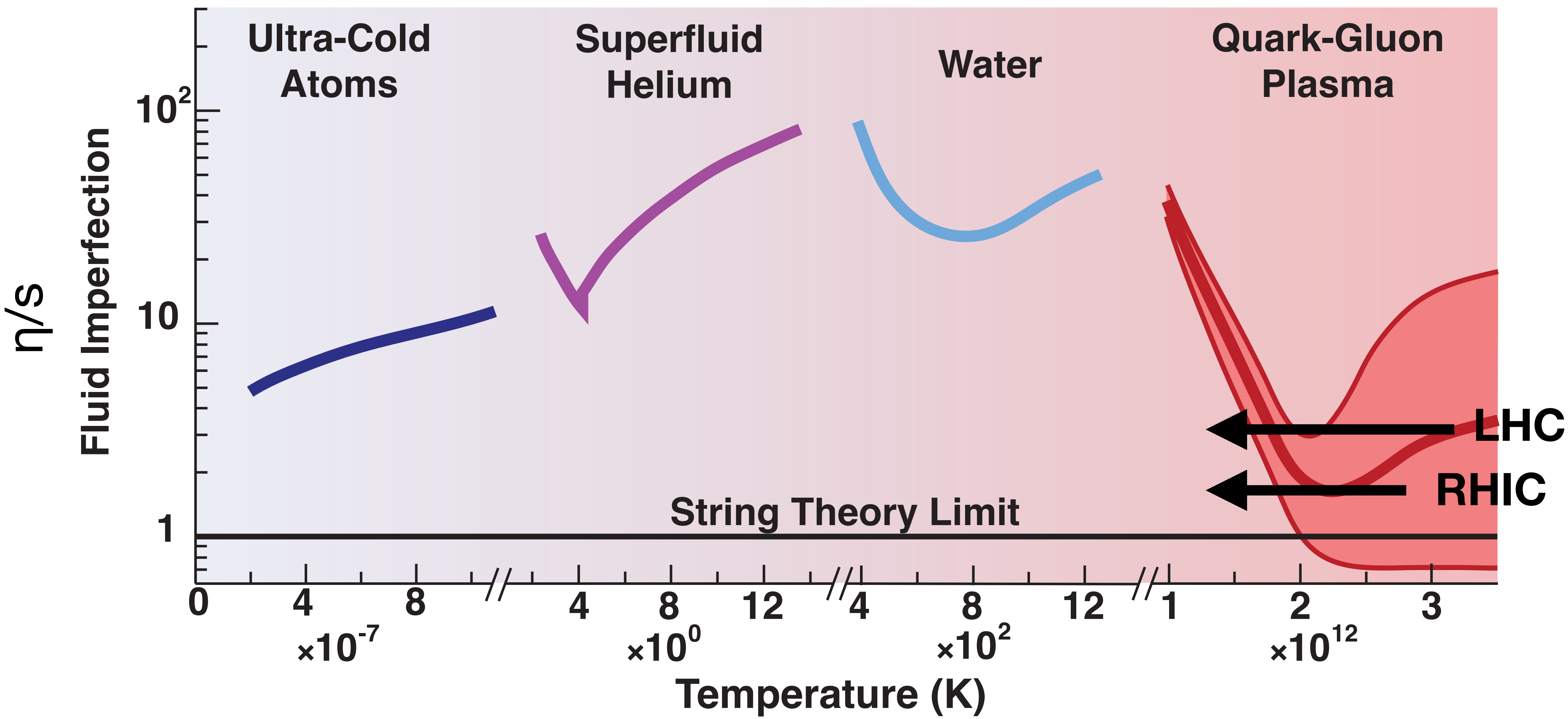
Viscosity near Phase Transitions



Many systems have minimum shear viscosity to entropy density near phase transformation

Quark-Gluon Plasma is not yet well constrained on this question

Viscosity near Phase Transitions



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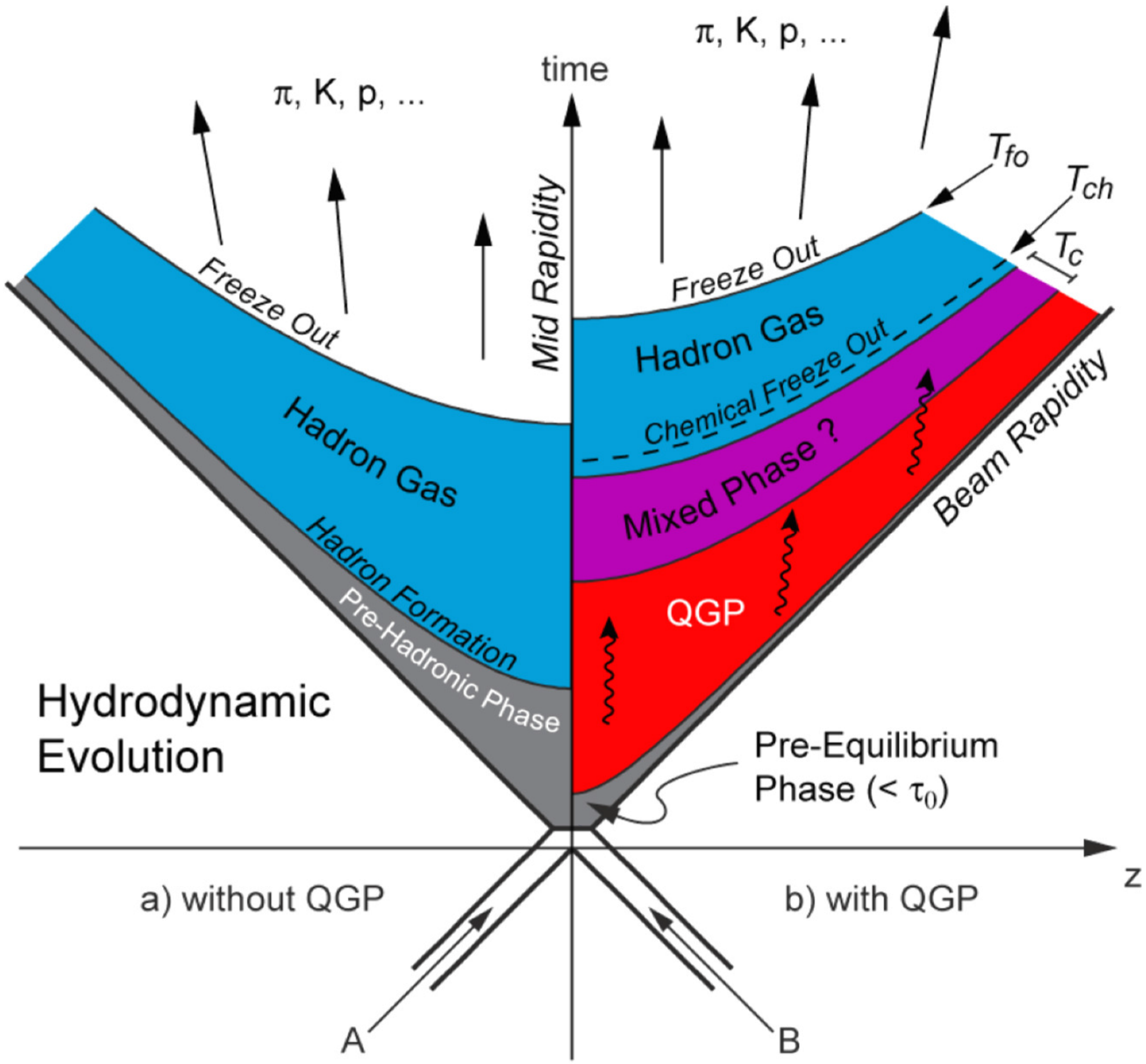
Quark-Gluon Plasma is not yet well constrained on this question

Space-Time Evolution



Kinetic Freeze Out (~10-15 fm/c)

Chemical Freeze Out (~7 fm/c)

Hadron Gas

Phase Transition (~4 fm/c)

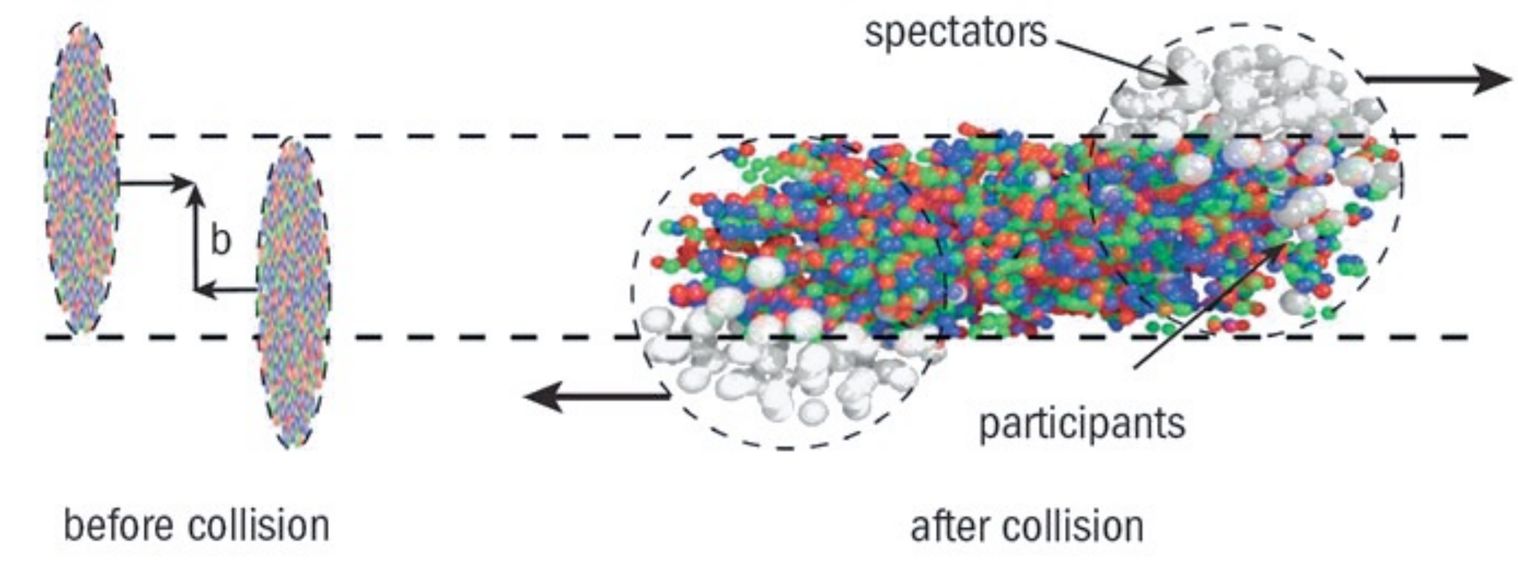
QGP

Thermalization (~0.6 fm/c)

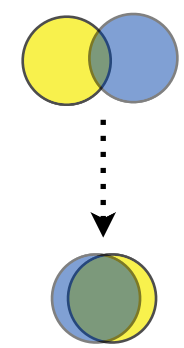
Nuclear Crossing (~0.1 fm/c)

***values for RHIC at 200 GeV**

Event Geometry Controls



Impact parameter studied via **centrality** selection



Large impact parameter
→ peripheral events, ≲100%

Small impact parameter
→ central events, ≳0%

Measured at large pseudorapidity

Tool: Glauber Monte Carlo simulation

Simple geometric description of A+A

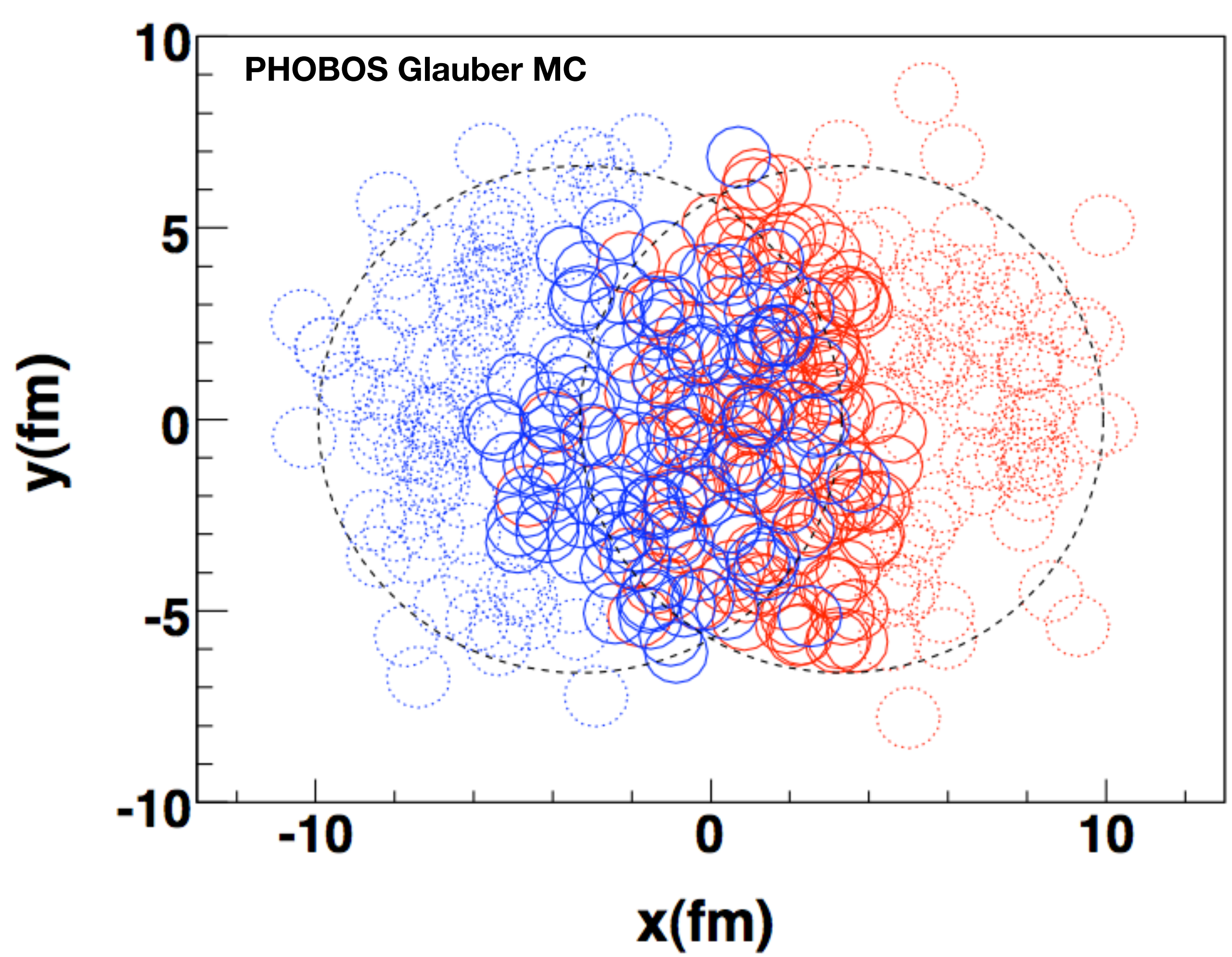
Includes statistical fluctuations

Number of Participating Nucleons, N_{part}

~ system size

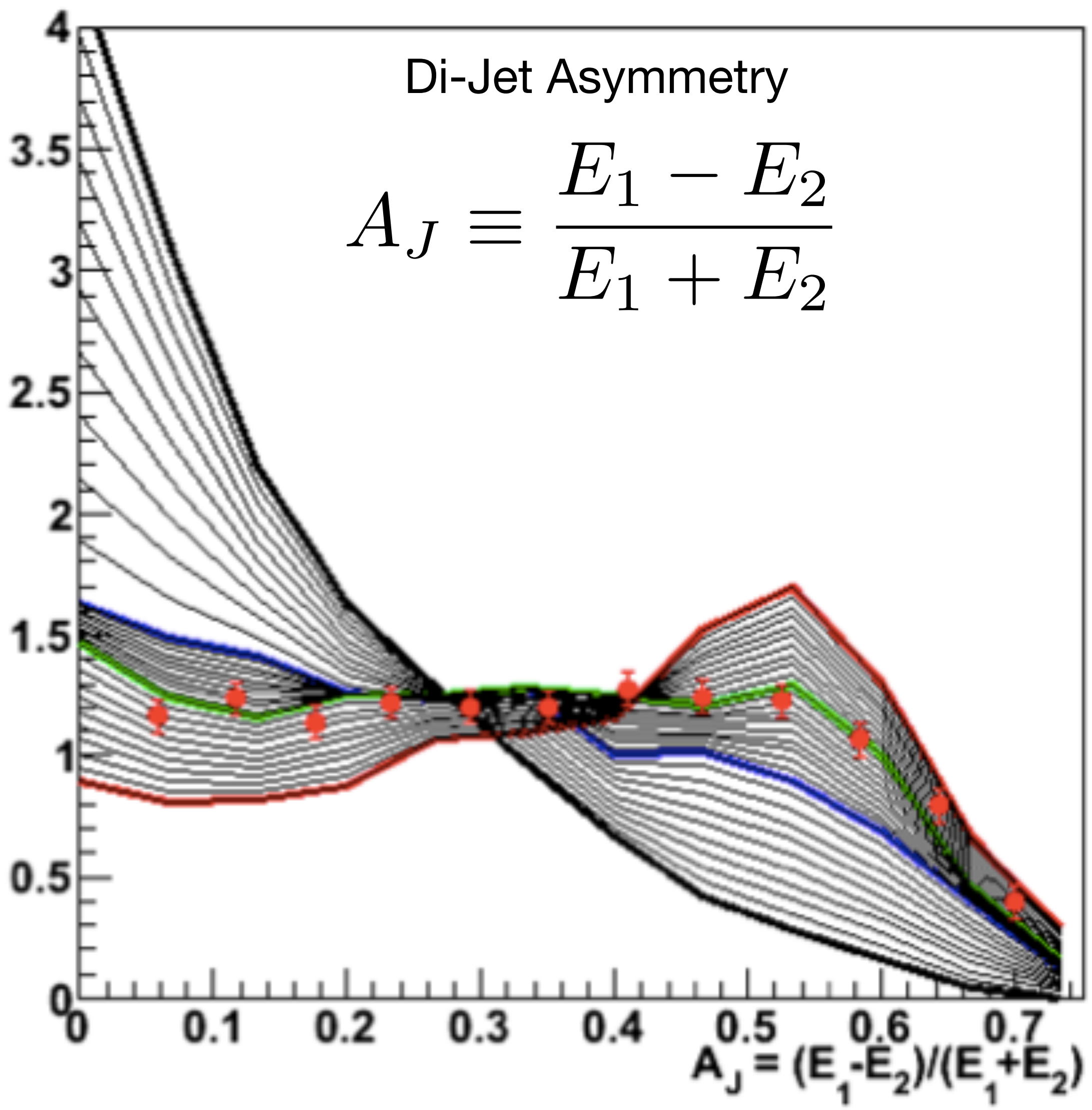
Number of Binary Scatterings, N_{coll}

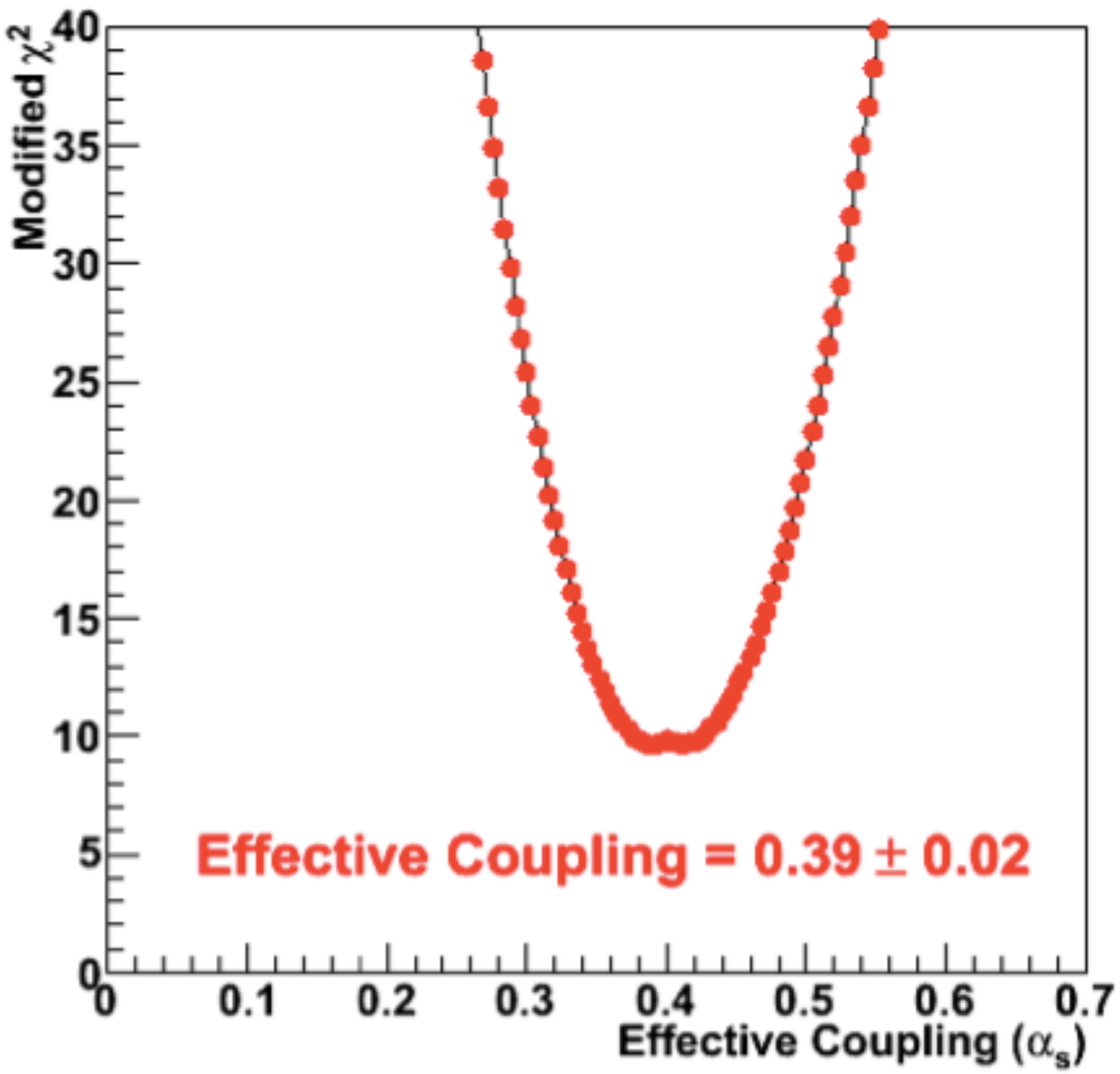
~ hard process cross-section



Information on Medium Properties

Using Coleman-Smith's dijet asymmetry the effective coupling is varied, how well can our projected measurement for 35 GeV jets with R = 0.3 constrain this parameter.

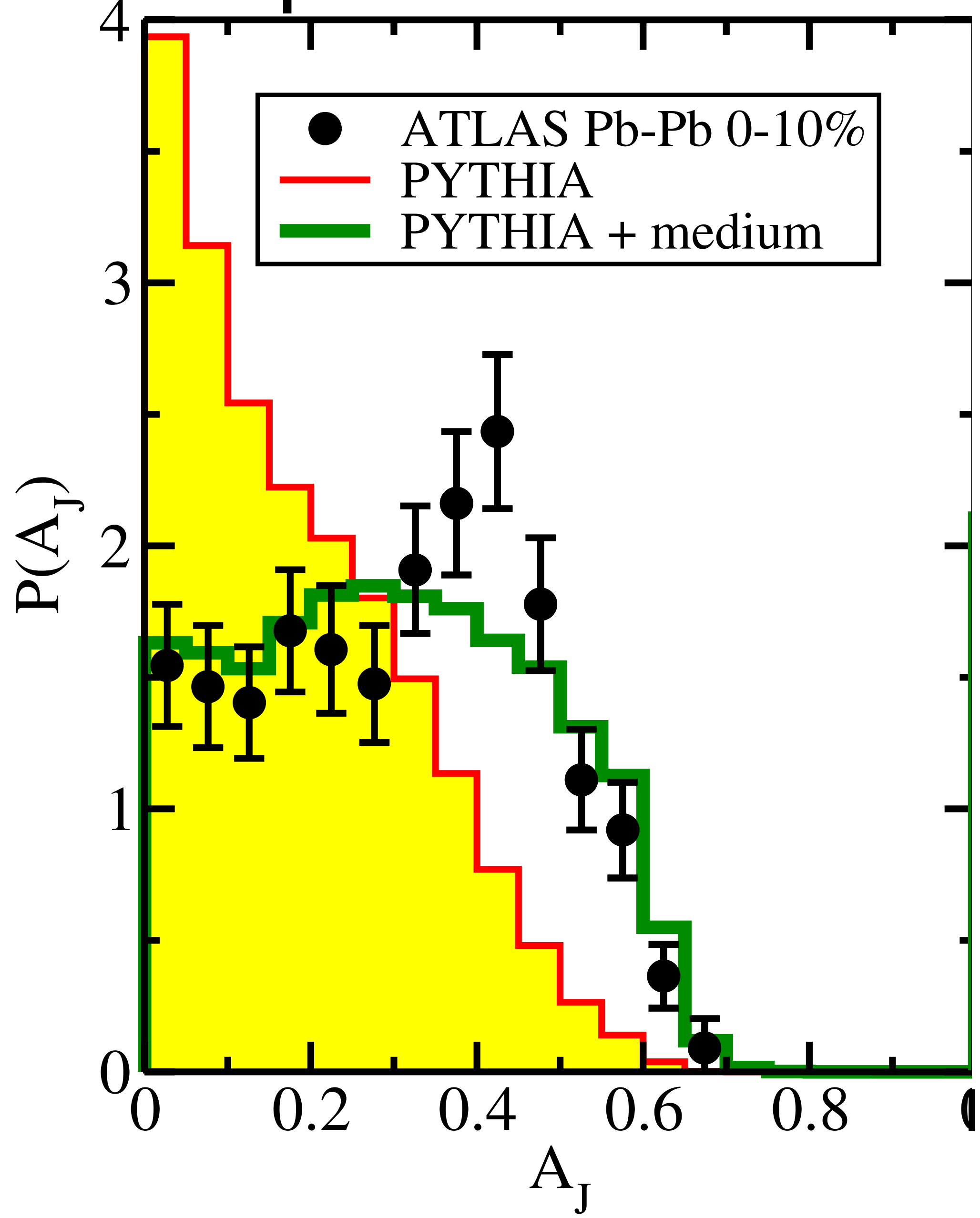




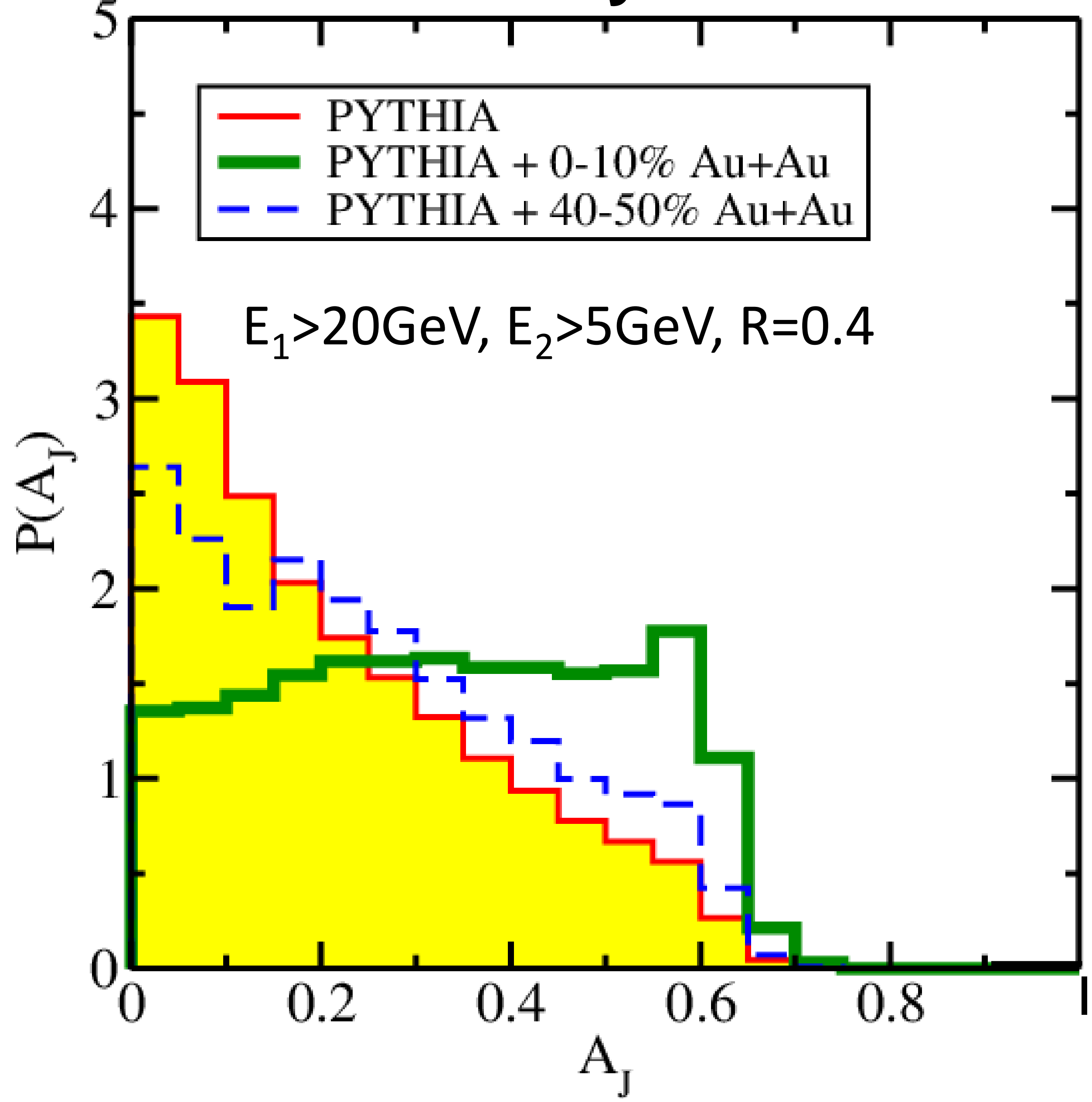
Of course, many observables need to be included since there is more than one unknown. The key is over-constraining the problem

Interaction of jet with medium

Comparison to LHC data

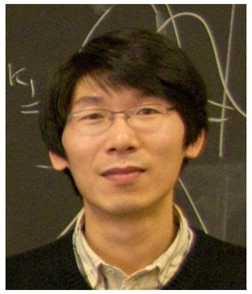


Distribution of AJ at RHIC energies

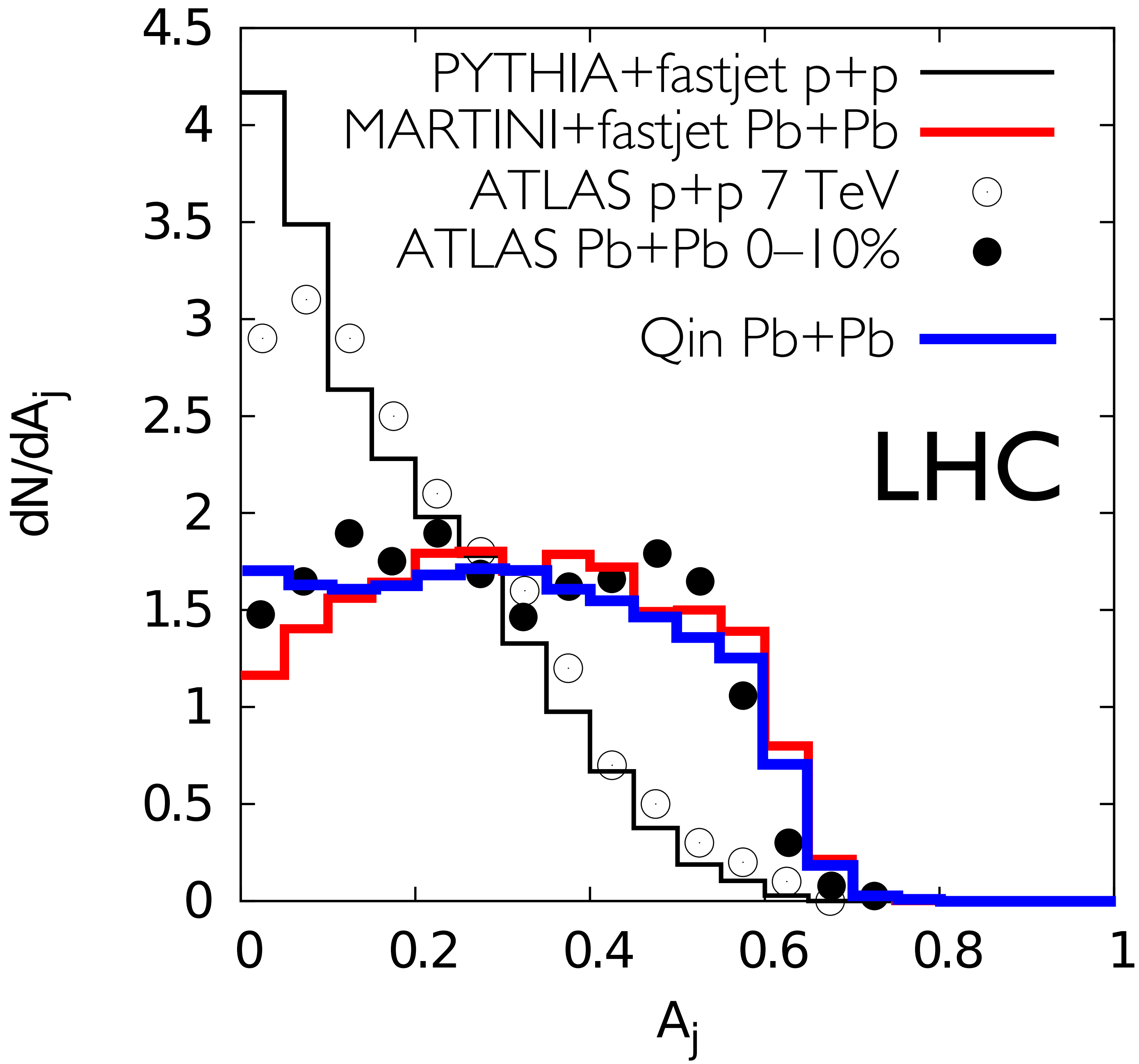


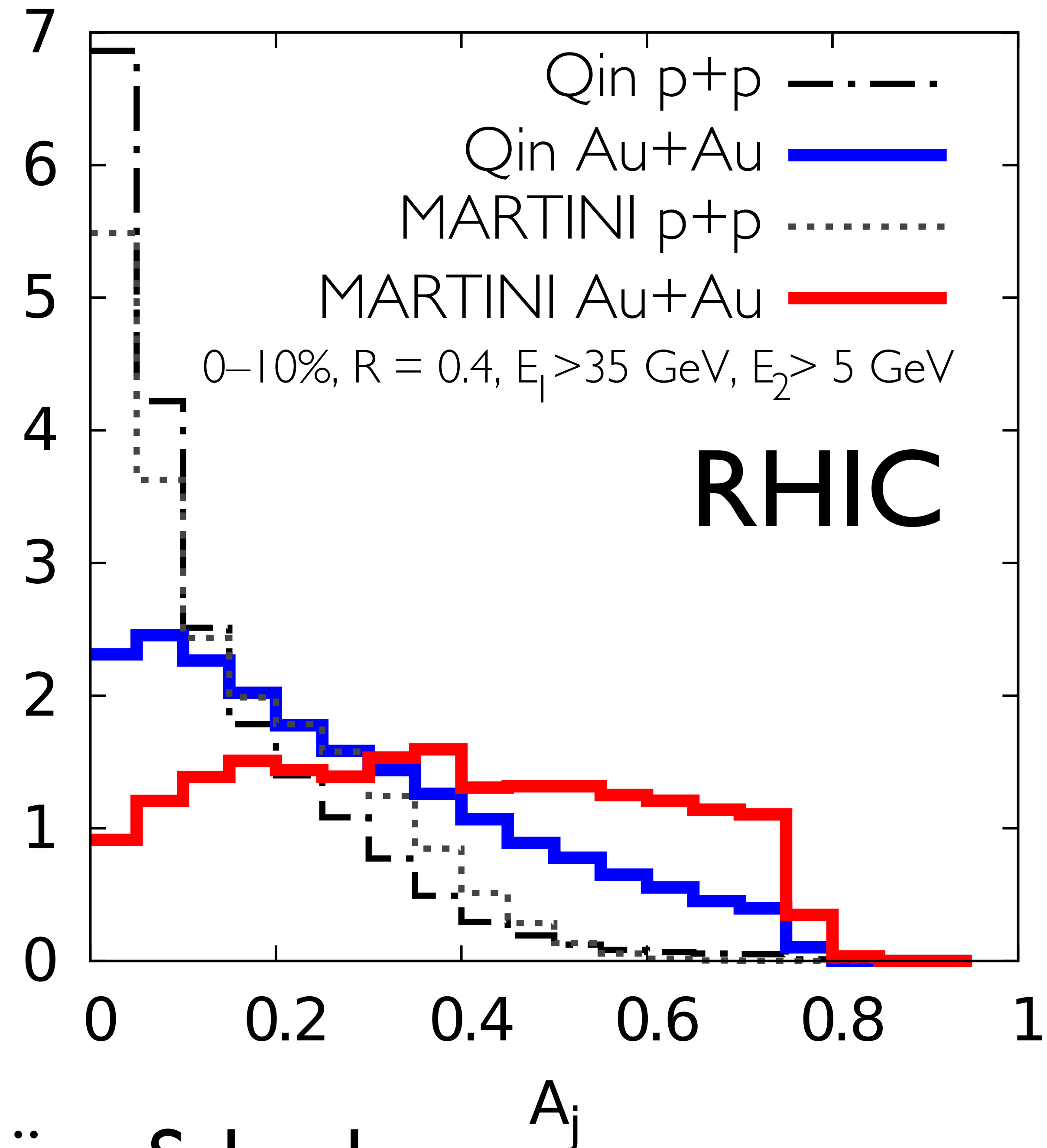
Guang-You Qin, Berndt Muller

PRL 106, 162302 (2011)



Same at LHC, different at RHIC





MARTINI: Björn Schenke

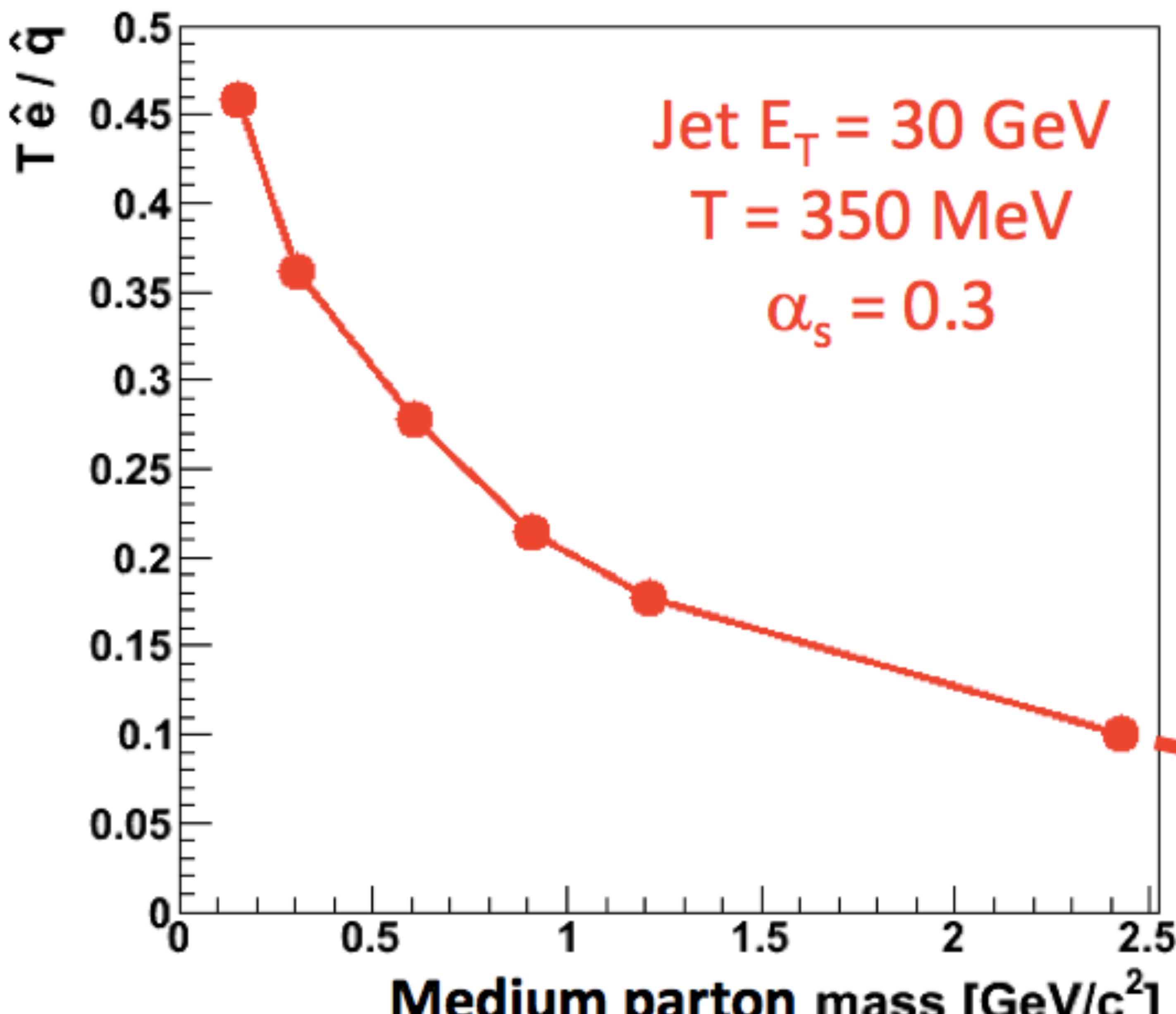
QGP Constituent Mass Dependence

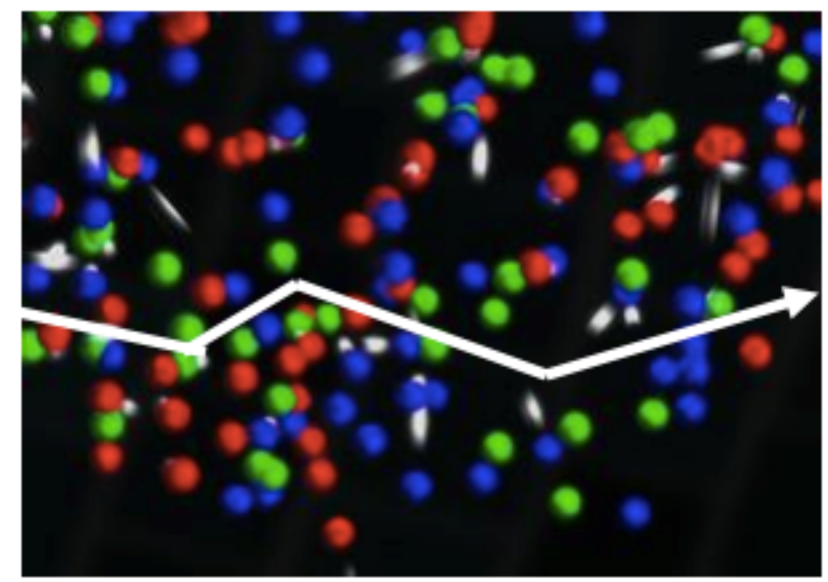
C. E. Coleman-Smith* and B. Müller
Department of Physics, Duke University, Durham, NC 27708-0305

http://arxiv.org/abs/arXiv:1209.3328

qhat → scattering of leading parton → radiation e-loss

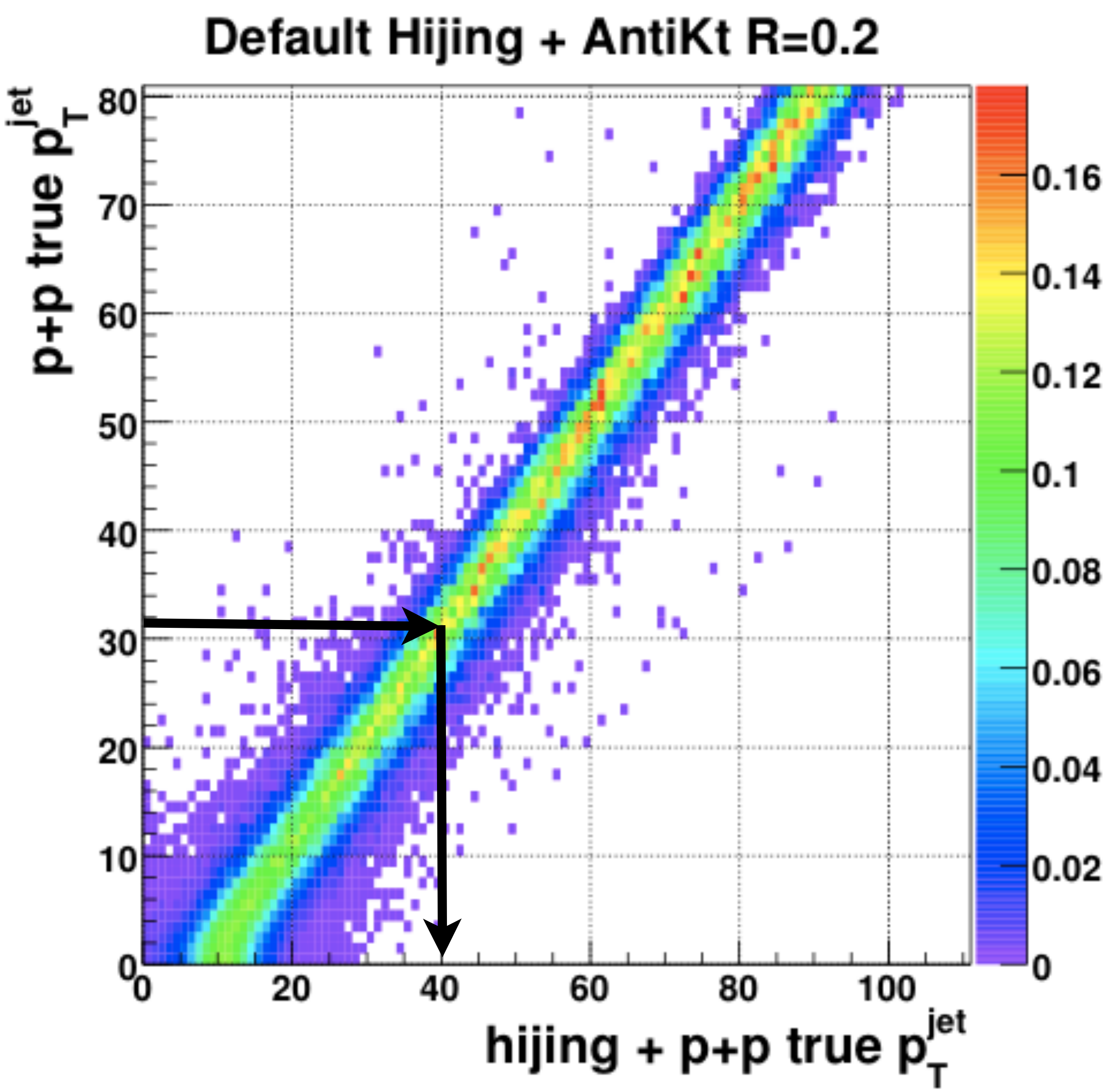
ehat → energy transferred to the QGP medium

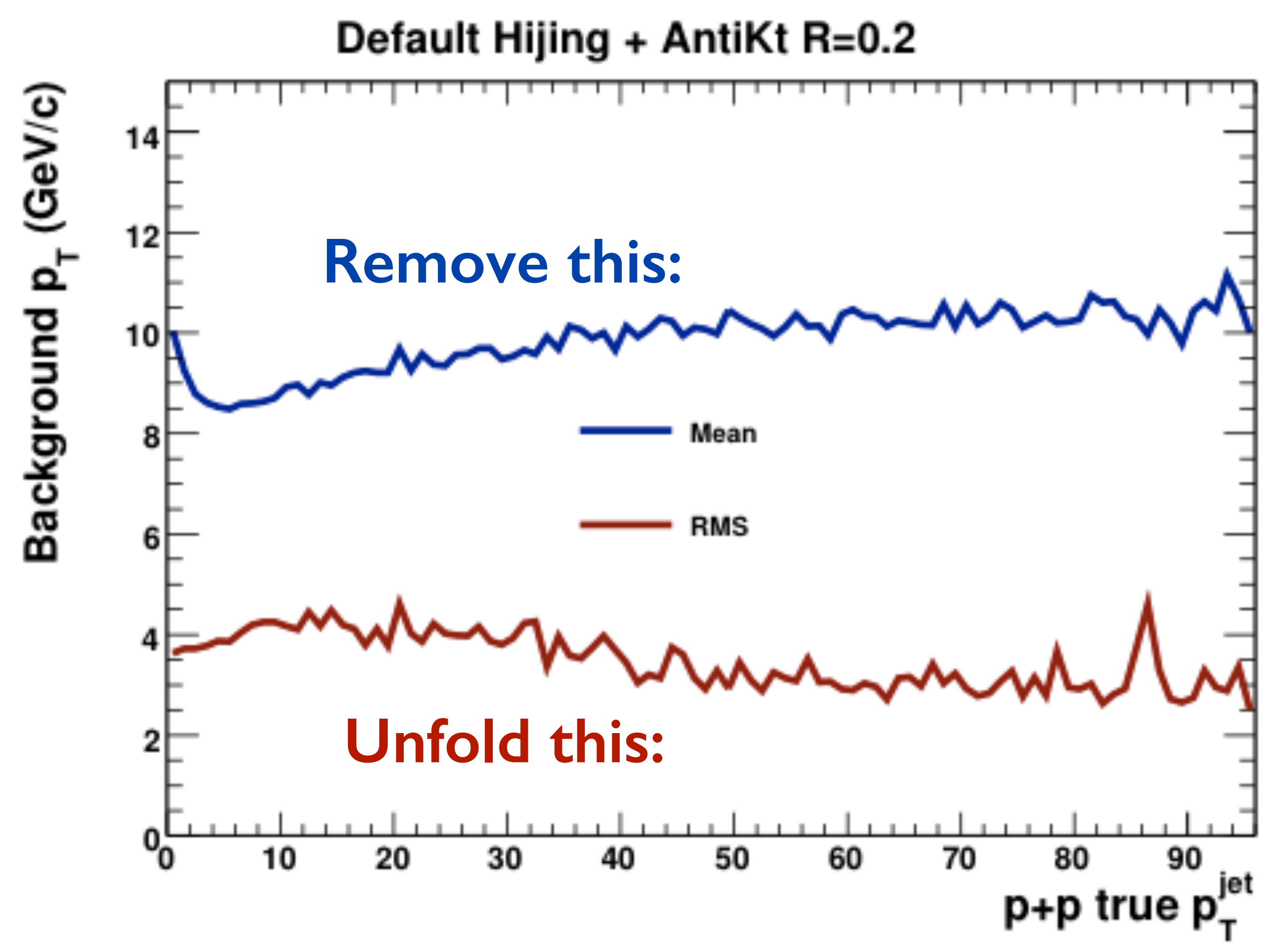




Limit of infinitely massive scattering centers yields all radiative e-loss.

Resolution: Underlying Event Impact





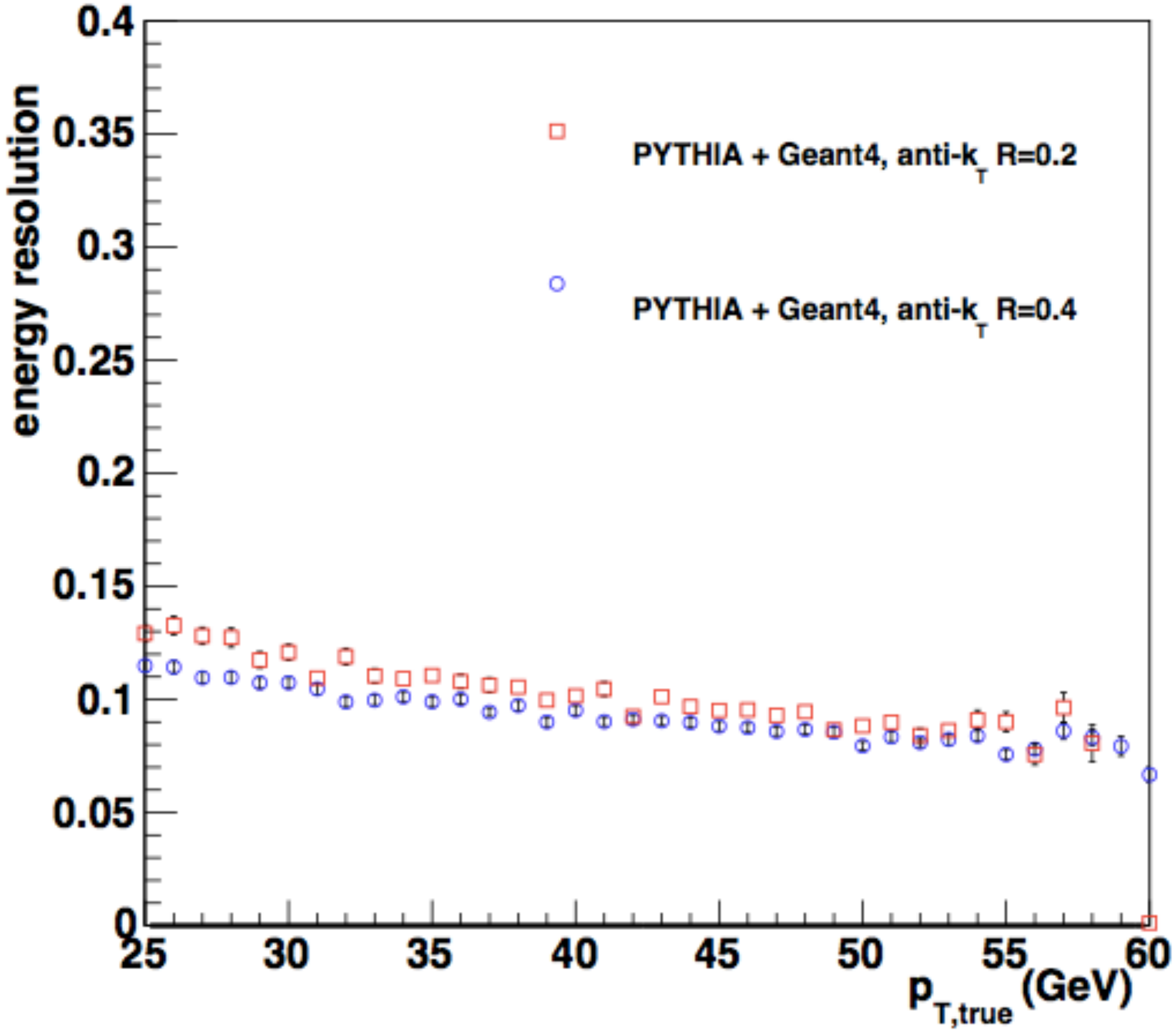
A 30 GeV embedded jet picks up ~10 GeV from the background to become a 40 GeV reconstructed jet

Subtract: ~10 GeV/c per jet
Unfold: ~3.5 GeV/c of smearing

~7 GeV/c of smearing at R=0.4
Comparable to HCAL resolution

More on jet subtraction:
PRC 86, 024908 (2012)

Jet Performance: p+p

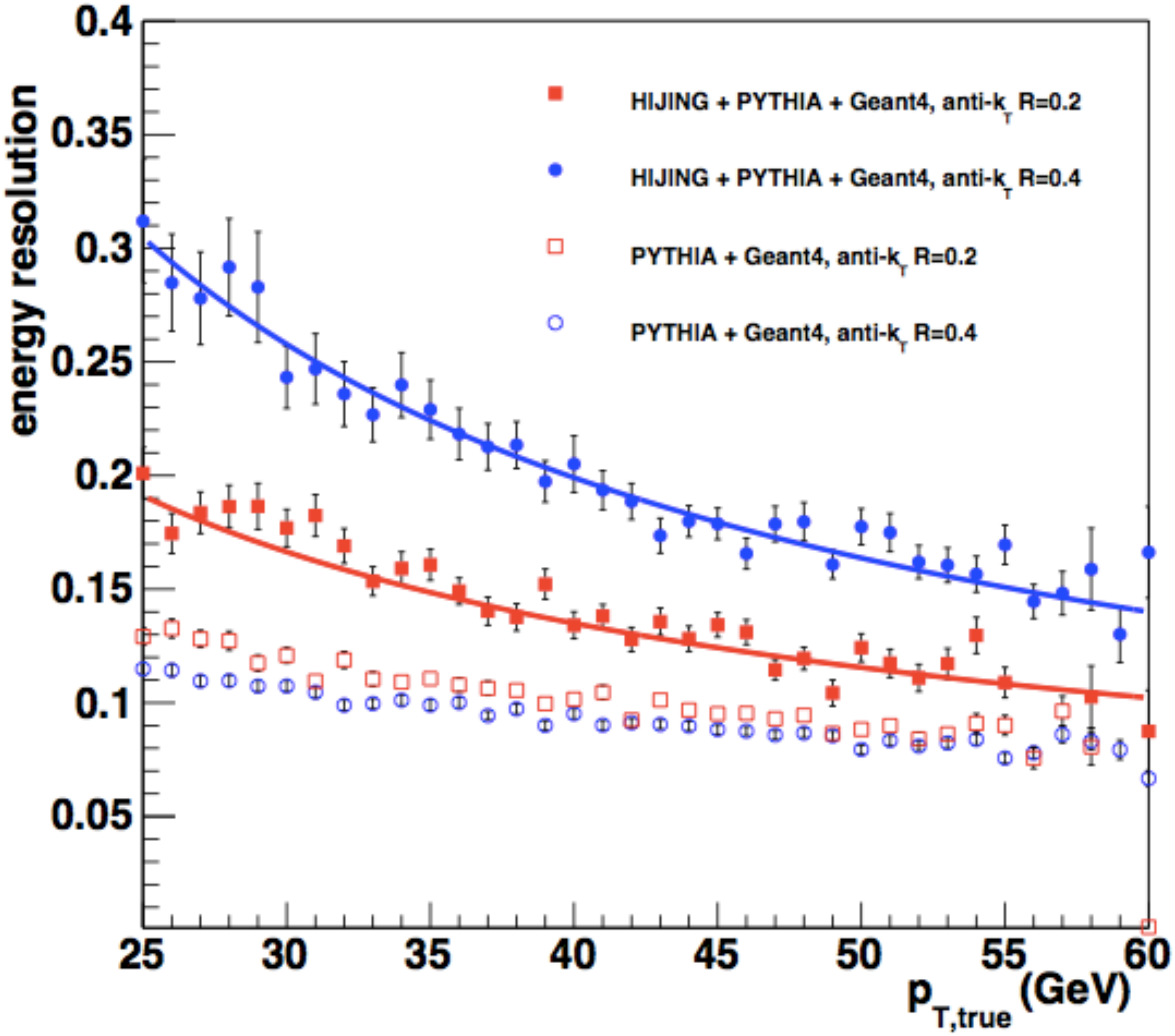


R=0.2: 65%/√E
R=0.4: 60%/√E
both small constant term

these resolutions are substantially better than the required resolution, driven by very good HCal resolution

Jet Performance: A+A

PYTHIA events embedded into central HIJING events



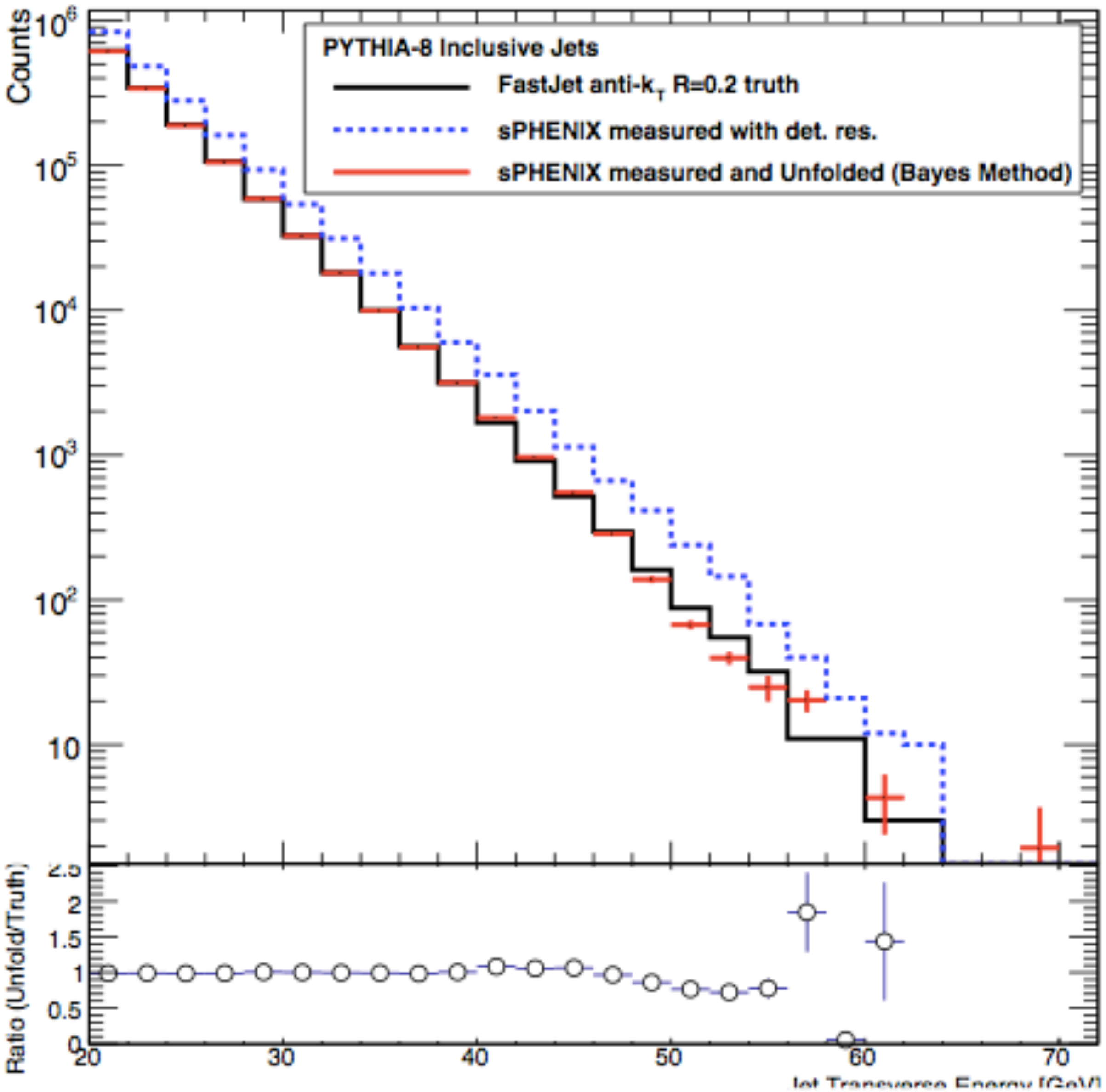
lines: p+p resolution ⊕ UE smearing

7 GeV for R = 0.4

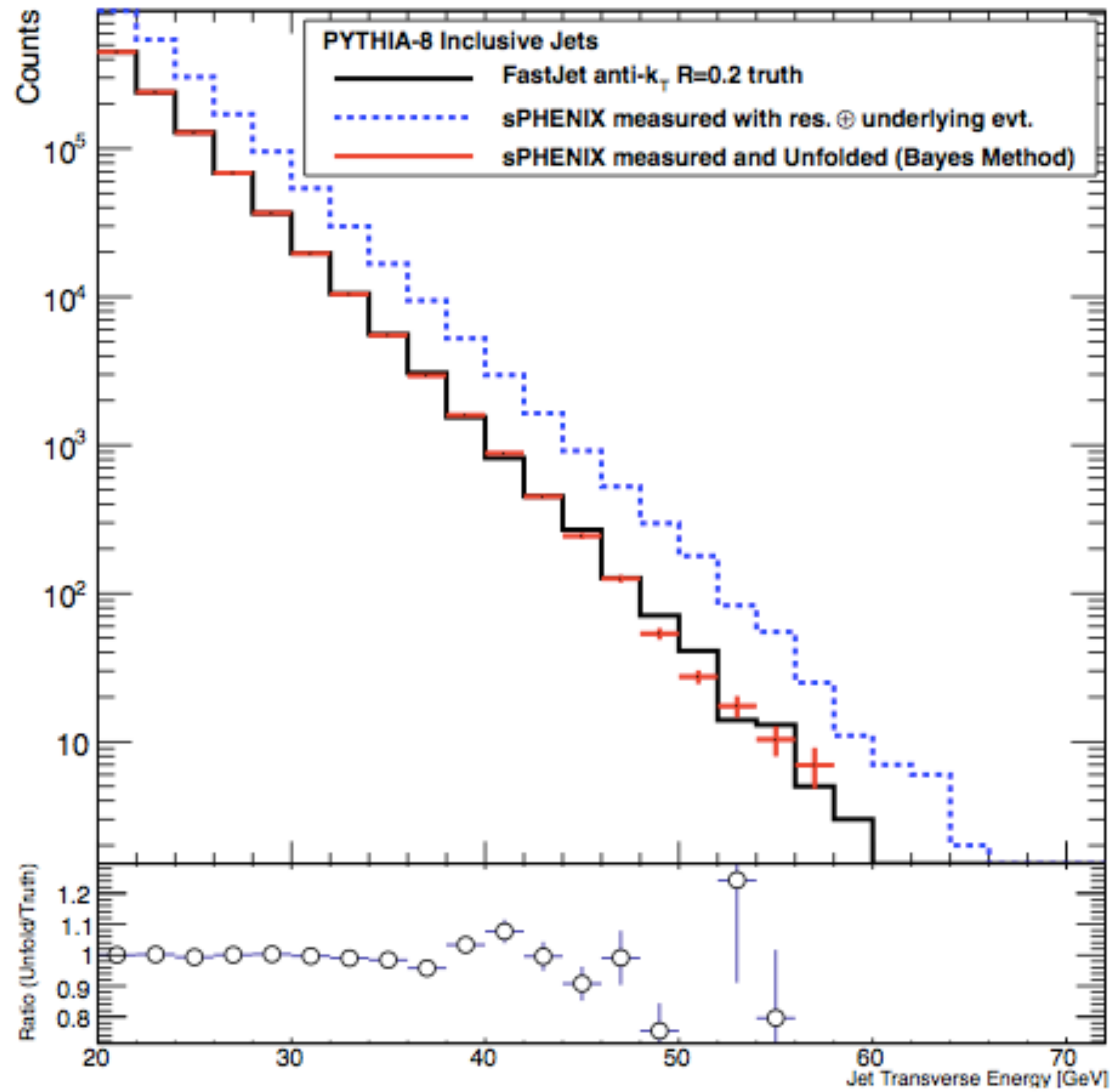
3.5 GeV for R = 0.2

Jet Spectra Projections

p+p



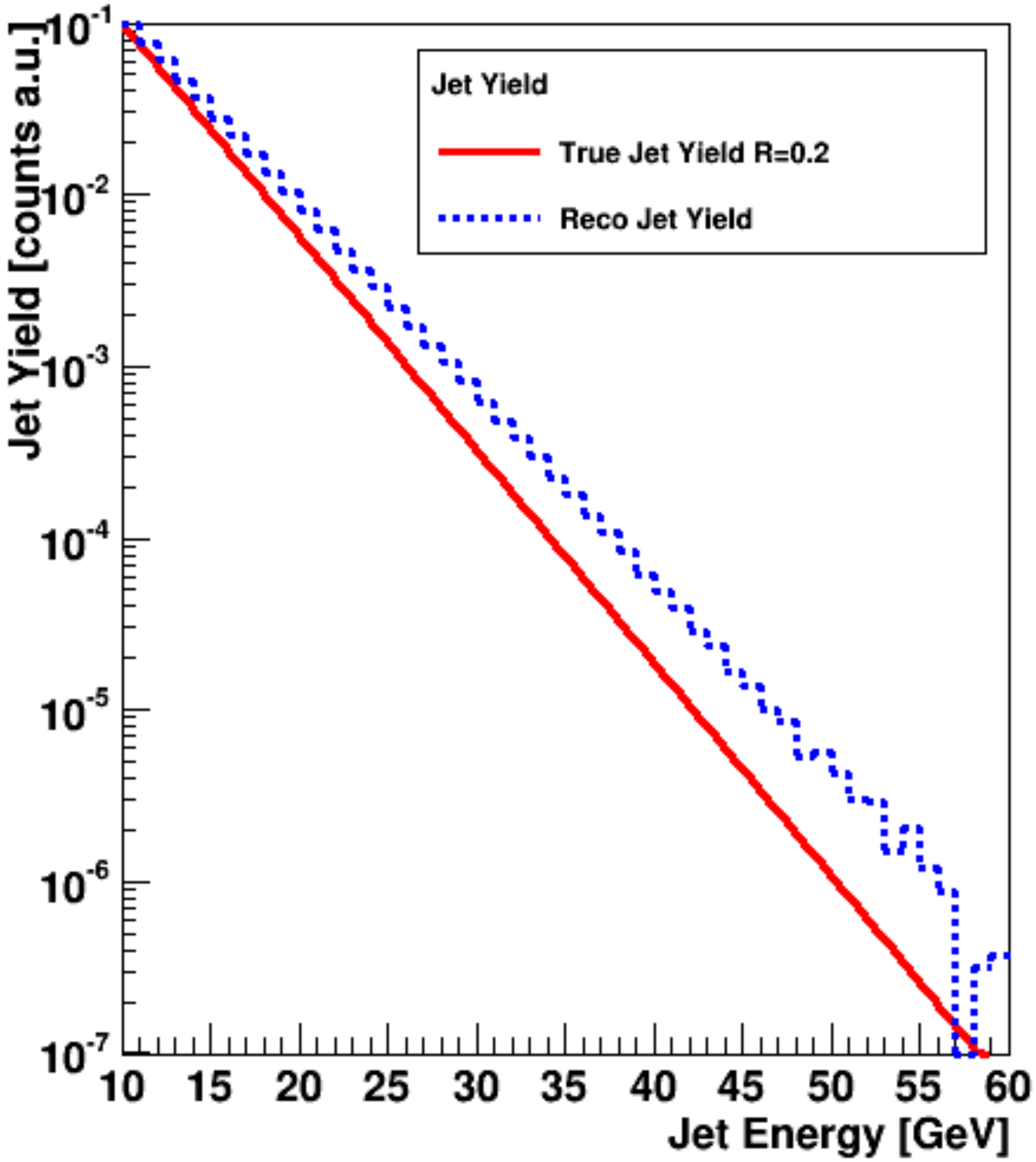
central Au+Au

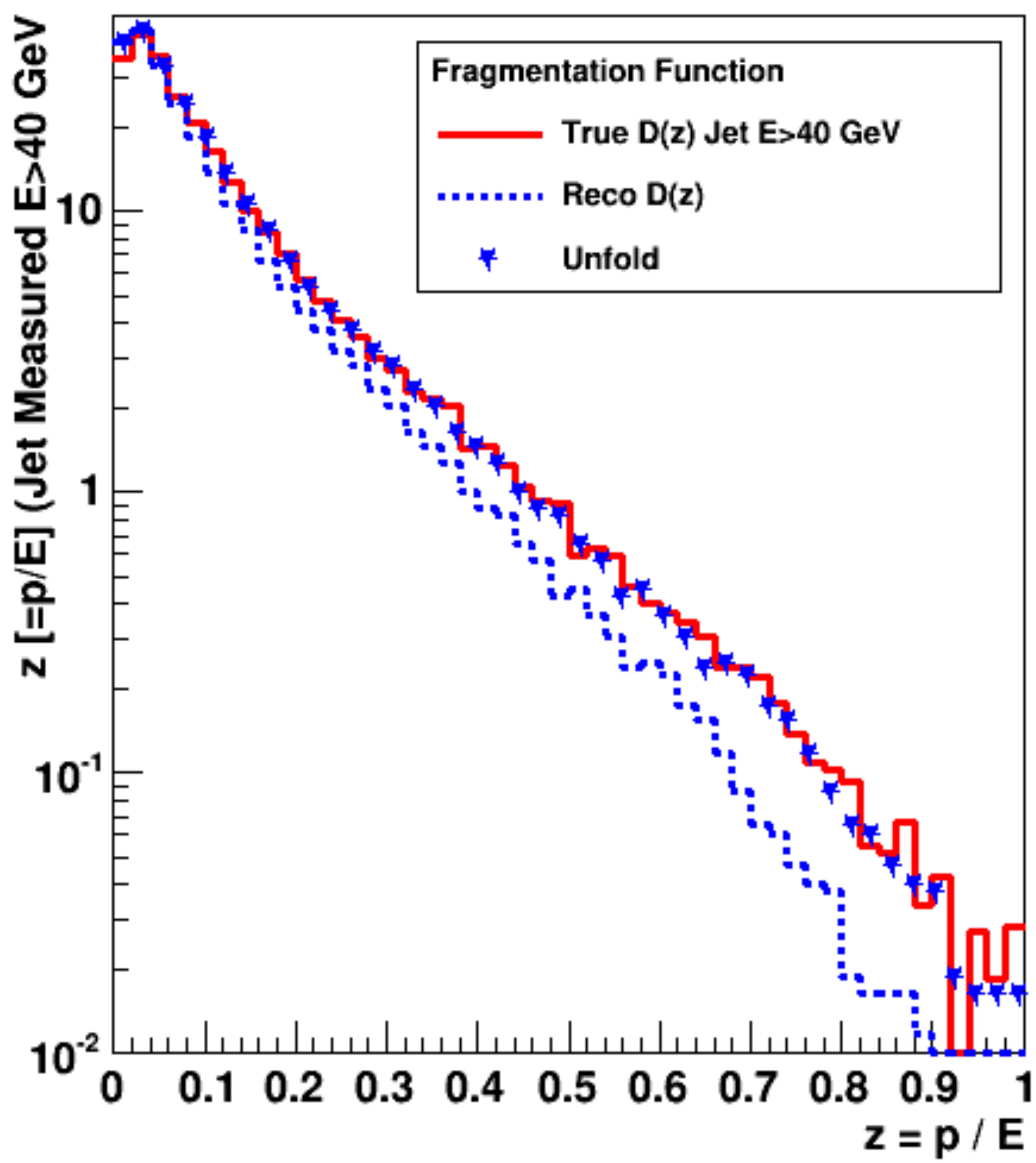


resolution **shifts** exponential spectra out in p_T

red shows **unfolded** result which **agrees with truth**

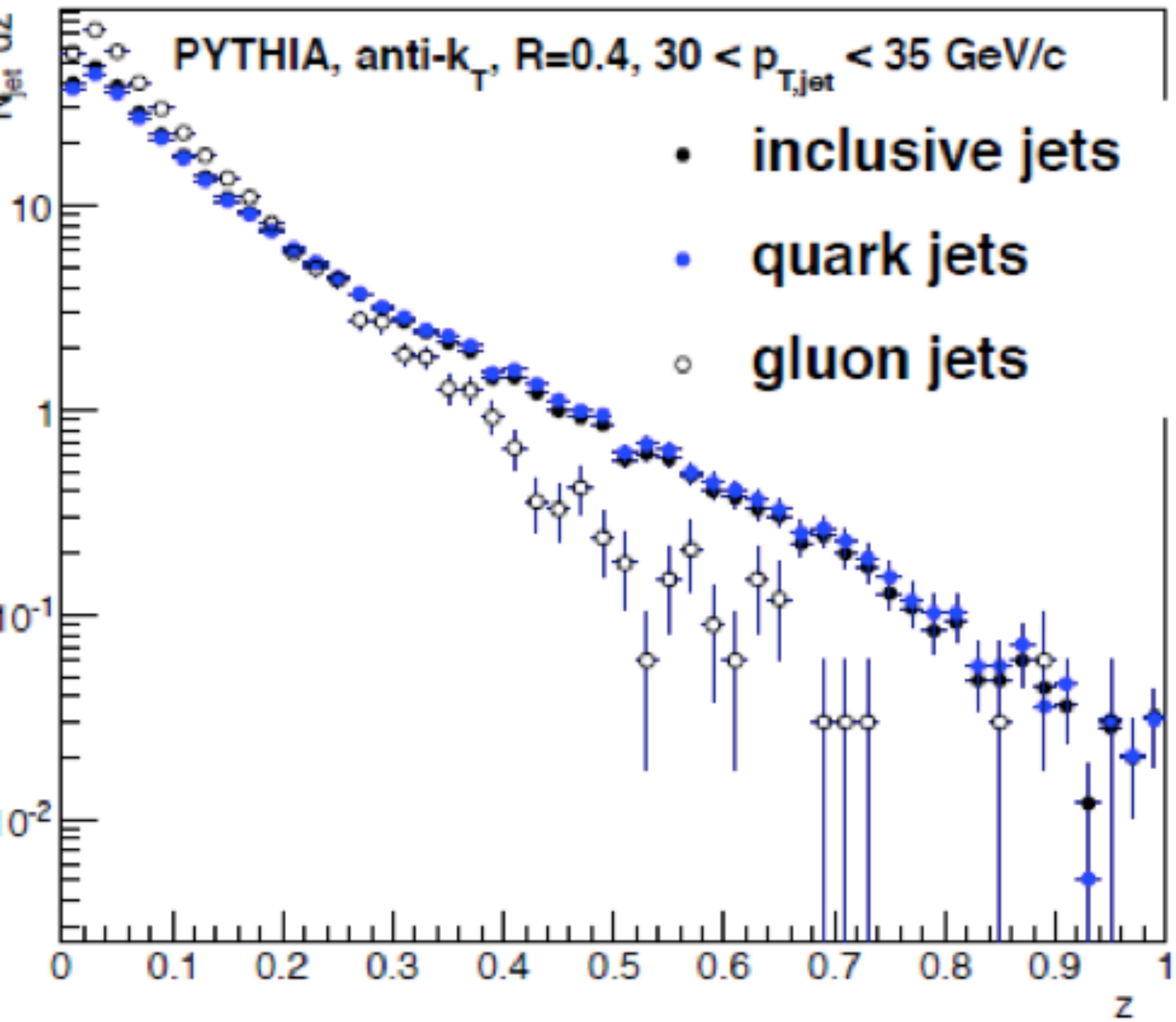
Longitudinal Unfolding

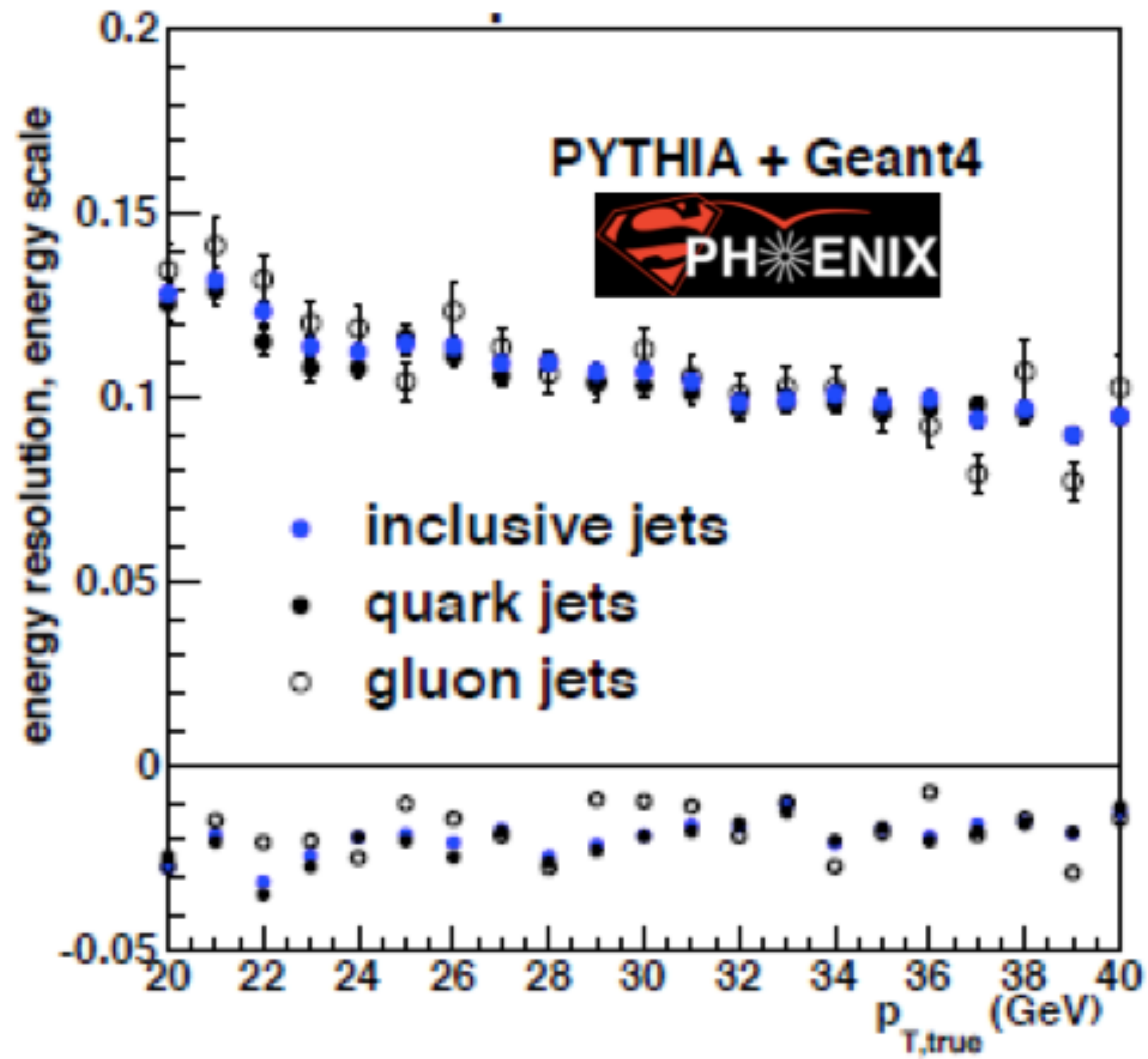




Flavor Dependence

Quark and Gluons have very different fragmentation functions

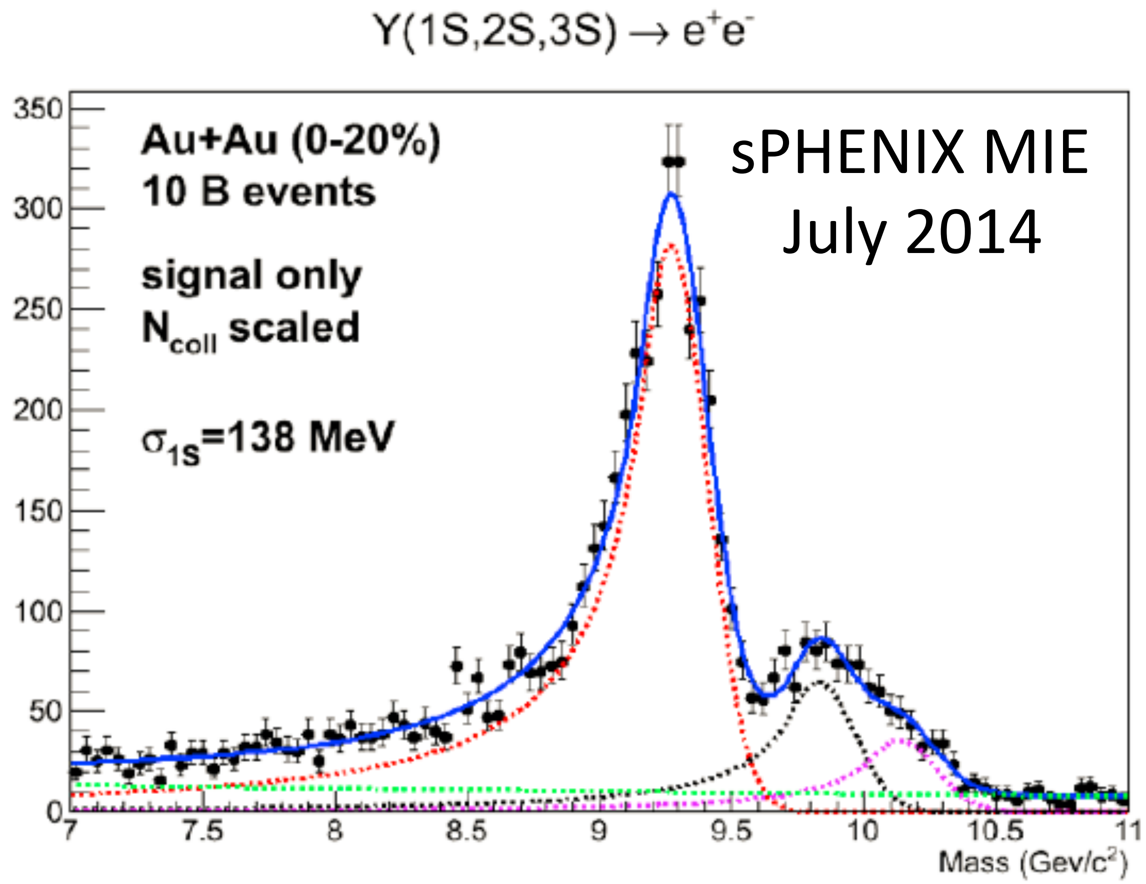


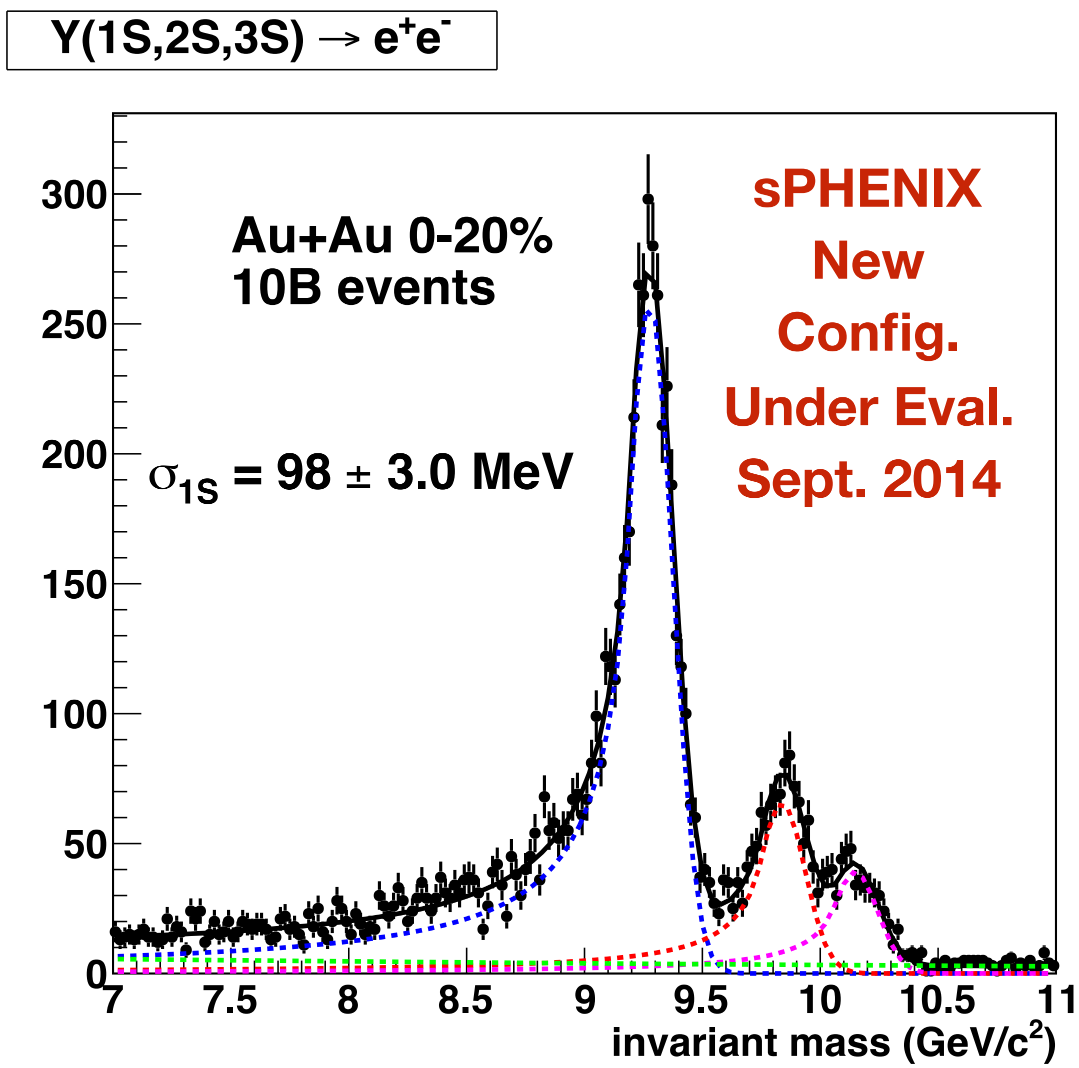


sPHENIX calorimetric measurement gives the same energy scale and resolution.

Critical for extracting longitudinal redistribution of energy.

Tracking Optimization I





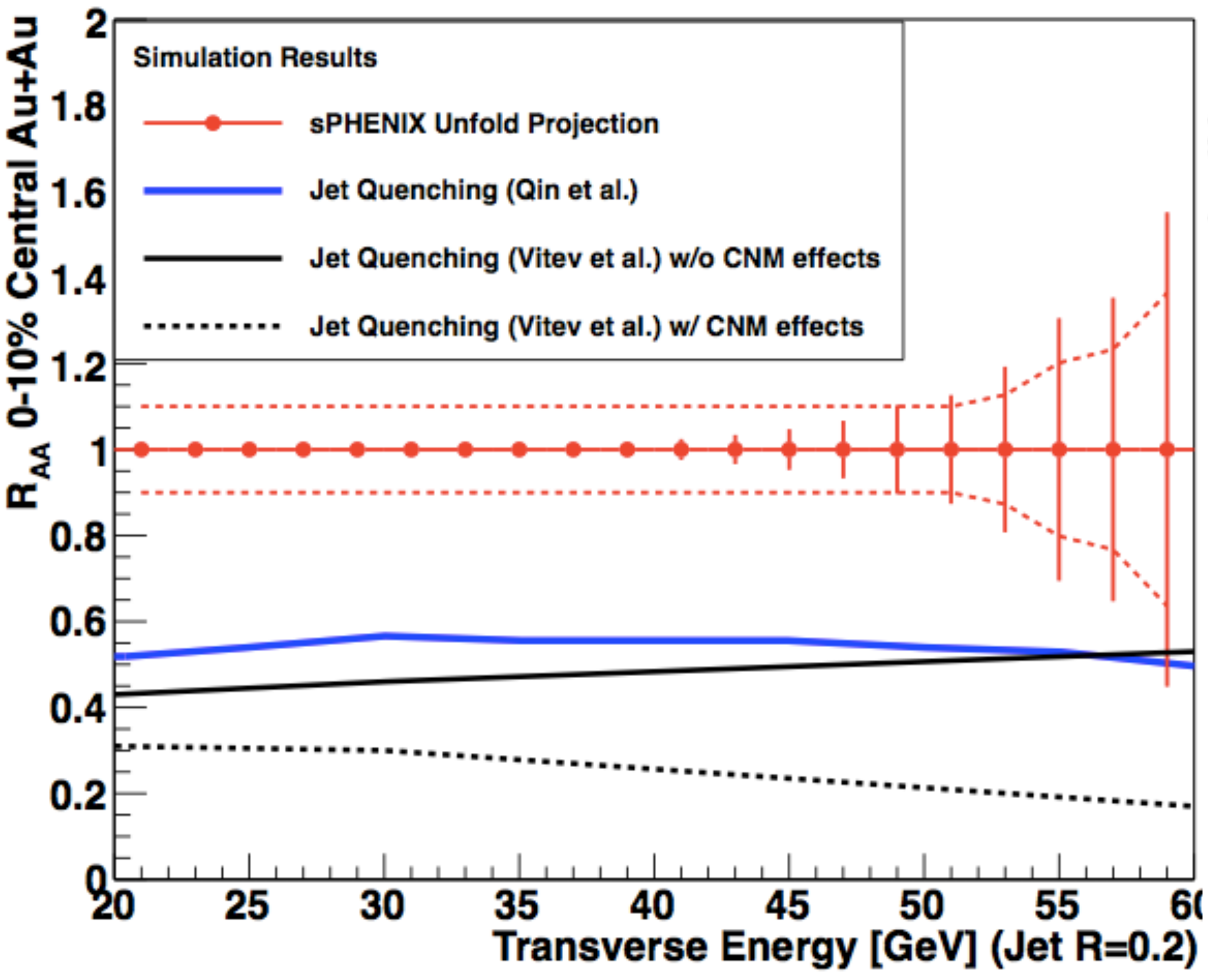
Mass resolution and expected counts (without backgrounds) from sPHENIX Proposal

Received suggestion at physics review to further optimize tracking and evaluate performance/cost tradeoff

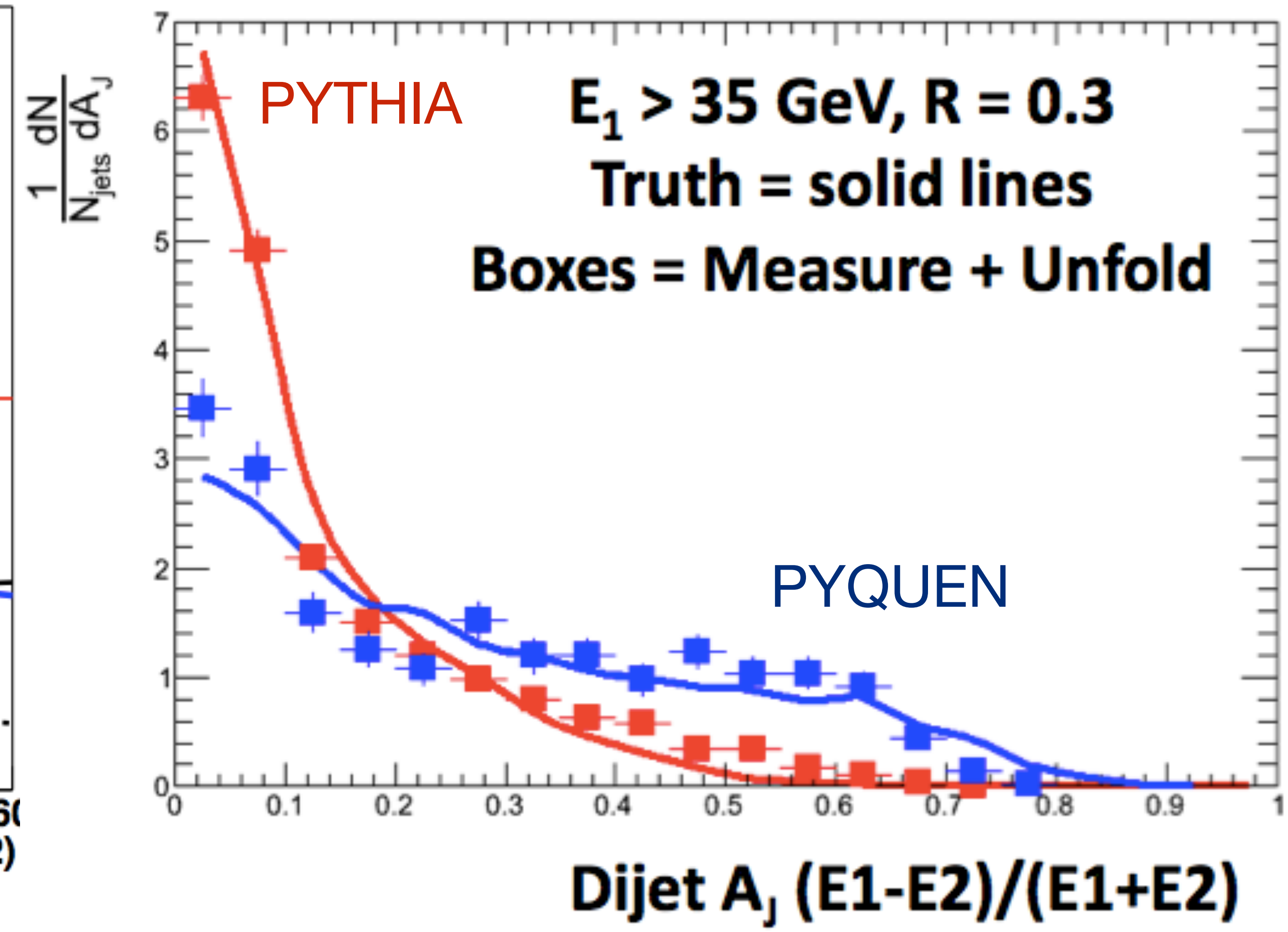
Revised design improve mass resolution

Figure of merit to preserve as we further revise the design

Projected jet R_{AA} and A_J



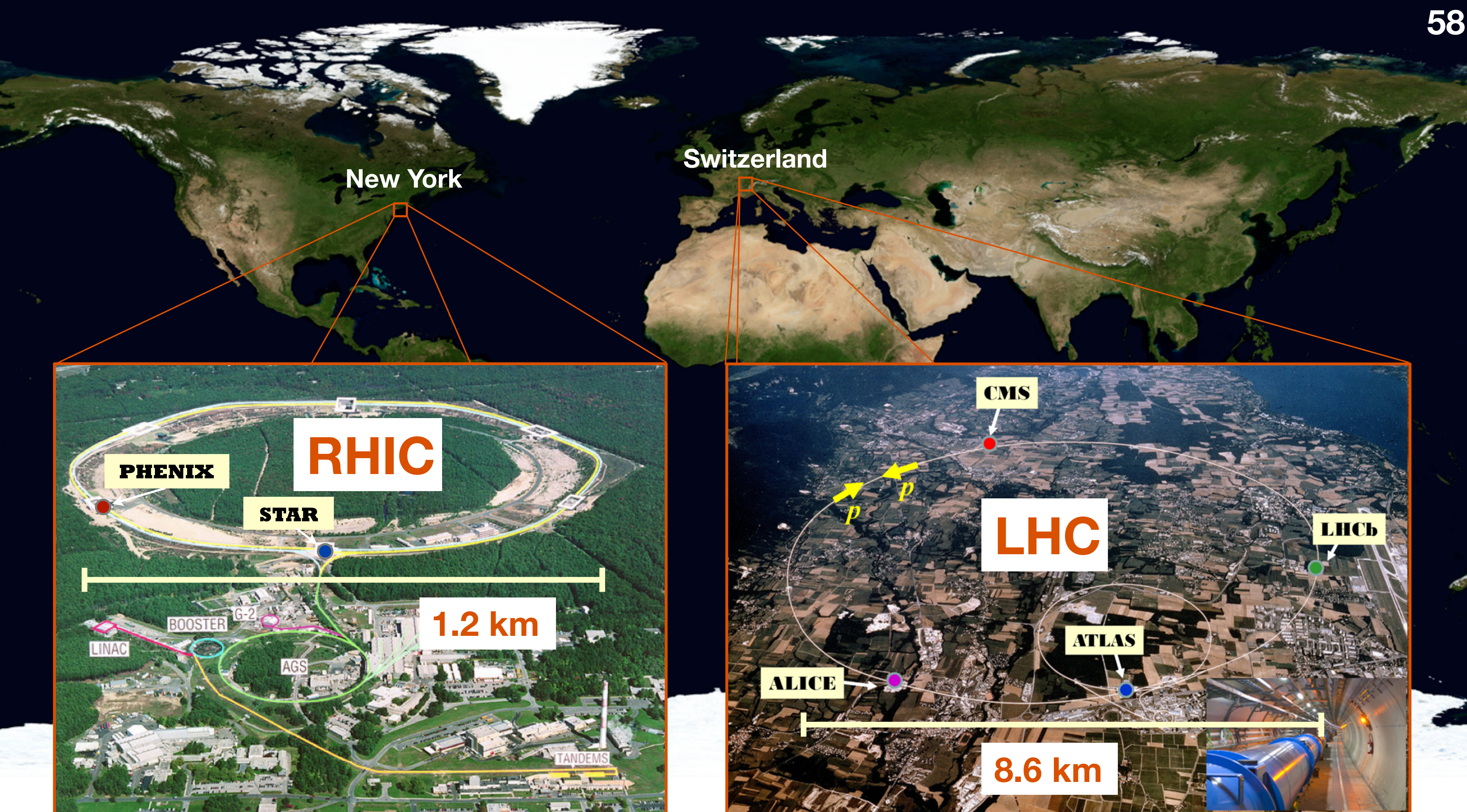
High precision out to 50 GeV/c



Easily resolvable A_J modification

Unfolding of detector resolutions under-control

Physics	Detectors	Requirements	
Full jet reconstruction	EMCal	$\sigma/E < 20\%/\sqrt{E}$	sPHENIX
	HCal	$\sigma/E < 100\%/\sqrt{E}$	
		$\Delta\eta \times \Delta\phi \sim 0.1 \times 0.1$	
		uniform within $\lvert\eta\rvert < 1$	
Direct γ, $p_T > 10\,\mathrm{GeV}/c$	EMCal	$\sigma/E \simeq 15\%/\sqrt{E}$	sPHENIX
		$\Delta\eta \times \Delta\phi \sim 0.03 \times 0.03$	
Jet-hadron	VTX 4 layers	tracking $p_T < 4\,\mathrm{GeV}/c$	Current PHENIX
	Solenoidal field		sPHENIX
High-z FFs	Jets as above	EMCal and HCal	sPHENIX
	Tracking	$\Delta p/p \simeq 2\%$	Future Option
Tagged HF jets	Jets as above	EMCal and HCal	sPHENIX
	DCA capability	Current PHENIX VTX	Current PHENIX
	Tracking	$\Delta p/p \simeq 2\%$	Future Option
Heavy quarkonia	Electron ID		
	EMCal	$\sigma/E \simeq 15\%/\sqrt{E}$	sPHENIX
		$\Delta\eta \times \Delta\phi \sim 0.03 \times 0.03$	
Separation of Υ states	Preshower	e/π rejection	Future Option
		fine segmentation	
	Tracking	$B = 2T$	sPHENIX
		$\Delta p/p \simeq 2\%$	Future Option
π^0 to $p_T = 40\,\mathrm{GeV}/c$	EMCal	$\sigma/E \simeq 15\%/\sqrt{E}$	sPHENIX
		$\Delta\eta \times \Delta\phi \sim 0.03 \times 0.03$	
	Preshower	2γ separation	Future Option
		fine segmentation	



beam	energy (GeV)
$\vec{p}+\vec{p}$	62 - 510
(d,He^3)+Au	200
Cu+Cu	22 - 200
Cu+Au	200
Au+Au	7 - 200
U+U	193

beam	energy (GeV)
p+p	7000-8000
p+Pb	5020
Pb+Pb	2760

Resolution: Background Subtraction

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Method for separating jets and the underlying event in heavy ion collisions at the BNL Relativistic Heavy Ion Collider

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